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M.V. ARCTIC - PROPULSIVE PERFORMANCE
INTERIM REPORT PREPARED FOR
TRANSPORTATION DEVELOPMENT CENTRE
MONTREAL

By

Melville Shipping Ltd.
Esso Plaza, East Tower
Suite 1900
425 First Street S.W.
Calgary, Alberta
T2P 3L8

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PROJECT TEAM

The project team for Melville Shipping Ltd. was composed of:

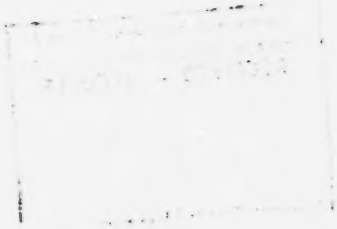
Mr. R.A. Dick

Mr. E.W. Thompson

Mr. P.J. Wyld

Dr. H.C. Cheung

and others



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17 Abstract

This Interim Report was prepared at about the halfway stage of a project to investigate the Propulsive Performance of the MV Arctic. The evaluation is based upon detailed analysis of the data gathered by the ship's instrumentation system during Arctic voyages and trials over the three year period 1979 to 1981. The report defines the scope of the database, describes the analysis methodology employed and provides typical examples of torque and thrust spectra recorded whilst the vessel operated in various transiting modes from open water to heavy icebreaking. Preliminary examination of these spectra indicate a negligible risk of the occurrence of shaft fatique failure even under the worst ice transiting conditions.

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17. Résumé

Ce rapport provisoire concerne le projet de recherche sur le rendement propulsif du cargo brise-glace Arctic, lequel projet était à moitié achevé au moment de la rédaction. Cette évaluation s'est fondée sur l'analyse approfondie des données recueillies par le système de saisie de données installé à bord, au cours des périples et des essais arctiques effectués sur trois ans, de 1979 à 1981. Ce rapport décrit le contenu de la base de données, traite de la méthode d'analyse utilisée et illustre par des exemples le spectre des couples et poussées enregistrées dans diverses conditions de fonctionnement depuis la navigation en mer libre jusqu'à la charge de glaces épaisses. Un examen préliminaire de ces paramètres montre la faible probabilité d'une défaillance de l'arbre due à la fatigue, même dans les pires conditions de fonctionnement.

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1.0 INTRODUCTION

The M.V. ARCTIC, an ice-capable bulk carrier of 28,000 DWT, was designed by Camat International Ltd. and constructed by Port Weller Dry Dock Ltd. The vessel was built in accordance with the Canadian Arctic Shipping Pollution Prevention Regulations (CASPPR) for an Ice Class 2 vessel, and to the rules and regulations of Lloyd's Register of Shipping with notation Ice Class 1A Super.

The ARCTIC has traditionally operated a shipping service from Nanisivik Mine in Strathcona Sound on Northern Baffin Island and to Little Cornwallis Island to northwest Europe between June and November. The vessel is propelled by a 11,014 KW MAN main propulsion diesel engine fitted to a LIPS controllable pitch propeller in a nozzle of Wageningen 19A type. The principal particulars of the M.V. ARCTIC are shown in Table 1.

The vessel is a joint venture between government and industry, and when built, was the most powerful and largest ice capable cargo vessel in the world. One of the most important aspects of the joint venture is to further Canadian expertise in Arctic ship design and operation by utilizing the ARCTIC as a test vehicle. (Ref. 1). The operational experience of the ARCTIC, in Arctic service, has been constantly evaluated and reported upon to provide a data base for research on future Arctic ship design and navigation.

The vessel was equipped with a comprehensive computerized data acquisition system to record operational data while navigating in ice with respect to the ship performance and the behaviour of the hull structure and propulsion system responses.

A voluminous data bank of the ARCTIC's operations records has been gathered during the three Arctic operating seasons, 1979-81, and through a number of dedicated ship performance tests performed in ice-infested waters. The data collected is now available for detailed investigation.

Melville Shipping Ltd. was awarded a contract by the Department of Supply and Services, sponsored by the Transportation Development Centre, Transport Canada, to carry out a study of the propulsive performance data collected from the ARCTIC. The main objective of this study is to determine the effect of ice on the performance and strength of the main machinery, gear train, shafting and propeller of the vessel.

This interim report presents the work of data reduction and analysis which has been performed up to date for this project. The data collected during the period of July to November 1981 has been analyzed in detail. Over 100 events of ice/propeller interaction have been identified, with a series of computer programs developed for data reduction. Section 2.0 of the report provides an overview of the ARCTIC's data acquisition instrumentation system and the data base gathered. The methodology used in data reduction is presented in Section 3.0, and the results are briefly discussed in Section 4.0.

Length Overall (LOA)	209.55 m
Length Between Perpendiculars (LBP)	196.59 m
Breadth Extreme (B)	22.93 m
Depth Moulded (D)	15.24 m
Draft (Full) (H)	10.93 m
Displacement (Full)	38,104 tonnes
Installed Power	14,770 BHP (Metric)
a) Main Engine - M.A.N. 52/55A 14 Cylinder 450 r.p.m.	
b) Gearbox - Renk Single reduction, vertical offset, with 3.147 reduction ratio	
Propeller Diameter	5.27 m
a) Lips - Controllable pitch - four blades - single propeller - 143 r.p.m. located in Wageningen 19A nozzle with 25 mm tip clearance	
Bollard Pull at Full Power	160 tonnes
Classification - Lloyd's [✠ 100A1, Ice Class 1A Super, LMC]	
- Arctic Class 2 (CASPPR)	
Ballast Capacity	28,329 tonnes
Fuel Capacity	1,852 tonnes

TABLE 1

M.V. ARCTIC - PRINCIPAL PARTICULARS

2.0 DATA COLLECTION

2.1 Data Acquisition Instrumentation

The data acquisition system which was installed in the M.V. ARCTIC was controlled by a computer, the data being recorded in digital form. The system permitted the use of 256 data channels. The total sampling rate capability was over 1,765 samples per second and the rate of an individual channel was up to 1,000 samples/sec. The entire system comprised a variety of sensors, power suppliers, data bus, analogue to digital coverters, amplifiers, a Roim model 1603A computer system and a closed circuit television system.

Over 200 sensors were fitted to the vessel. Five specific areas of data were recorded, namely:

- Hull structure (structural strains and temperature)
- Propulsion system (engine room)
- Auxiliary systems (bubbler system and steering)
- Ship performance (ship motion data)
- Environment conditions (ice and meteorological data)

Figure 1 illustrates the layout of the data acquisition system. (Ref. 2). The central computer was located in the ship's laboratory and directed operations within the system with minimal operator participation. Peripherals of the computer system included a printer and two AMPEX high density magnetic tapes which allowed on-line examination and storage of the output of the sensors on to magnetic tape for subsequent analysis.

For propulsive performance measurements, the following parameters were measured by the instrumentation system:

- Shaft torque
- Shaft thrust
- r.p.m.
- Propeller pitch, command and response
- Fuel rack position
- Ship speed
- Propeller blade spindle torque

The propeller shaft torque was computed from the output of a strain gauge bridge mount on the shaft, transmitted to the non-rotating instrumentation through a telemetry system. A RENK thrust meter, installed in the shaft thrust bearing, provided an output proportional from which shaft thrust could be calculated.

Shaft and engine r.p.m. were recorded from outputs from the r.p.m. tacho generators. In most of the recording however, only the shaft r.p.m. signals have been collected. The pitch angle of the LIPS controllable pitch propeller was recorded from the output of a potentiometer fitted to the oil

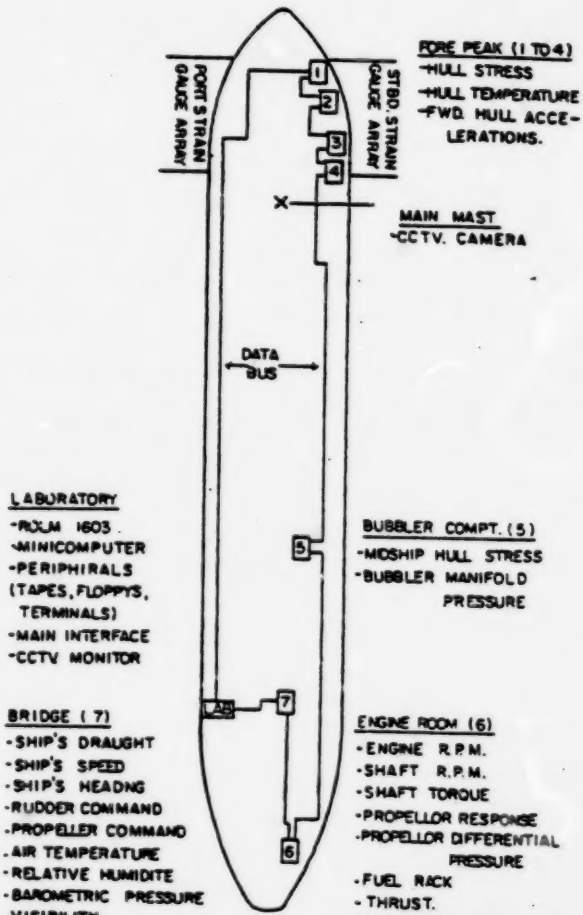

FIG. 1 LAYOUT OF THE M.V. ARCTIC

DATA ACQUISITION SYSTEM

distribution box on the propeller shaft. A similar device is used to obtain the combinator setting, the pitch angle ordered in the bridge.

The fuel rack position was monitored by a pick-up connected mechanically to the fuel rack control. The ship speed was measured by a SPERRY Doppler speed log.

A differential pressure transducer was fitted to the propeller pitch oil distribution box to read the differential oil pressure acting across the actuating system of the blade positioner. The total propeller blade spindle torque, although not measured directly, may be related to this hydraulic pressure measurement.

Table 2 summarizes the propulsion system sensors used in the ARCTIC and the range of measurement of each sensor.

2.2 Scope of Data Base

The data acquisition system has been extensively operated during voyages in the Arctic from 1979 to 1981 and four dedicated ice trials performed in 1980 and 1981. A total of 163 magnetic tapes of data have been recorded, providing a large data base pertinent to the ship's performance and response. The data base consists of about 250 hours of recording, of which more than 75% was made while the ship was navigating in ice-infested water.

The four dedicated ice trials were carried out respectively in the Saguenay River, Quebec (January 1980), Baffin Bay area from Navy Board Inlet to Strathcona Sound, NWT (October 1980), Lake Melville, Labrador (February 1981), and Admiralty Inlet, NWT (July 1981).

The ice trial program, in the Saguenay River, January 20 to 22 1980, comprised a set of discrete tests of speed/power variation and turning circles. The ice condition was first-year land fast, level ice, 0.3 - 0.5m in thickness, with a flexural strength about 0.35 MPa.

Nine data tapes, representing about 5 hours reecording, were collected on this dedicated trial using the computer-controlled data acquisition system.

The Baffin Island trial, held October 26 to 31, 1980, was performed when the vessel was navigating through 10/10 first-year ice in Navy Board Inlet, Lancaster Sound, Admiralty Inlet and Strathcona Sound. The ice thickness ranged from 0.2 to 0.5 m and the flexural strength ranged from 0.2 - 0.4 MPa estimated from measurements of ice temperature and salinity. Some 40 ship performance tests were carried out during this trial, including tests of speed/power, turning circles, breakout, backing and Kempf and Star manoeuvers. Twenty-two data tapes were recorded, covering a total period of over 30 hours.

The third ice trial of the M.V. ARCTIC was conducted in Lake Melville, Labrador, between February 27 and March 3, 1981. Data collection was carried out when the vessel was performing the following tests:

PARAMETER MEASURED	TYPE OF SENSOR	RANGE OF MEASUREMENT
Shaft Torque	Strain Gauge Bridge	0 - 1.8 MNm
Shaft Thrust	Renk Thrust Meter Type RCIK-3	± 1.2 MN
Propeller Pitch Response	Follow-Up Potentiometer	16° - Astern 22° - Ahead
Fuel Rack Position	Follow-Up Potentiometer	0 - 100% of Full Travel
Shaft RPM	Shaft Tachometer	60 - 200 RPM
Ship Speed	Sperry Doppler Speed Log	0 - 30 Knots
Combinator Setting	Follow-Up Potentiometer	+ 10 Ahead - 10 Astern
Propeller Pitch OD Box Differential Pressure	Pressure Transducer Selabs Type SE21/V	0 - 14 MPa

TABLE 2

PROPULSION SYSTEM SENSORS

- level ice speed/power
- rudder angle sensitivity
- level ice ramming
- ridge ramming
- channel breakout
- turning circle
- broken channel speed/power

Seventeen data tapes were recorded. The ice in Lake Melville was first-year, 10/10 fast ice of about 0.3 MPa flexural strength. Level ice thickness ranged from 0.6 to 1.0 m. Several ridges of consolidated ridge keel depths about 2 - 3 m were penetrated during the trial.

The fourth dedicated ice trial was a series of organized ramming tests conducted in Admiralty Inlet, July 7 - 8, 1981, during which 22 data tapes were recorded. The tests were performed at various speeds and ship trims, on first-year land fast, level and ridged ice. The level ice thickness was between 1.2 and 1.8 m, and the measured ice ridge keel depth were in the range of 2 - 5 m. The estimated ice flexural strength for this trial was 0.15 MPa.

Data recording during regular voyages was on a more continuous basis as compared to the recording for the dedicated trials, in which data collection was generally only taken place during the discrete test periods. Consequently, more data has been collected during the regular shipping voyages. Most of the voyage records were made when the vessel was transitting north of 60°N latitude in areas of Davis Strait, Baffin Bay, Lancaster Sound, Admiralty Inlet, Strathcona Sound, Navy Board Inlet, Pond Inlet, Barrow Strait and McDougall Sound. The data collection was concentrated on the first and last round-trips each year to Little Cornwallis Island and Nanisivik when the most significant ice conditions were encountered.

In addition, some data was collected during Atlantic crossings and manoeuvring in North Sea. This data provides a bench-mark of the ship's performance and response in open water.

Table 3 summarizes the status of the data collection over the years 1979 - 1981 on the performance of the propulsion system. The identification of the data tapes of each voyage or dedicated test are also included in the table.

As shown in the table, all the propulsion system sensor outputs were recorded at "real mode" for most of the time. Only during the first and second voyages of the 1980 season, the "peak mode" recording option was selected. The "real mode" recording of the data acquisition system provides the instantaneous digitized value of the sensor output signal when sampled, while the "peak mode" recording, through the use of a peak-holding circuitry, records the highest output signal of the sensor during the sampling interval.

VOYAGE	DATE	NO. OF TAPES RECORDED	TAPE I.D.	SAMPLING RATE (HZ.) SHAFT TORQUE	SHAFT THRUST	RPM	PROP. PITCH	FUEL RACK	SHIP SPEED
79-1	JUL/79	3	79-1-1 - 79-1-3	10	-	-	1	0.1	0.1
79-2 *	JUL/AUG/79	3	79-2-4 - 79-2-6	-	-	-	-	-	-
79-3 *	AUG/79	9	79-3-7 - 79-3-15	-	-	-	-	-	-
79-4 *	AUG/79	5	79-4-16 - 79-4-20	-	-	-	-	-	-
79-5	OCT/79	5	79-5-21 - 79-5-25	10	1	-	1	0.1	0.1
79-6	OCT/79	5	79-6-26 - 79-6-30	10	1	-	1	0.1	0.1
79-7	NOV/79	9	79-7-31 - 79-7-39	10	1	-	1	0.1	0.1
SAGUENAY RIVER TR.	JAN/80	9	80-T1-1 - 80-T1-9	10	10	-	1	0.1	0.1
80-1	AUG/80	5	80-1-1 - 81-1-5	1*	1*	-	1*	1*	-
80-2	SEP/80	4	80-2-6 - 80-2-9	1*	1*	-	1*	1*	-
80-3	SEP/80	0	-	-	-	-	-	-	-
80-4	OCT/80	5	80-4-10 - 80-4-14	10	1	-	1	0.1	-
80-5	OCT/80	3	80-5-15 - 80-5-17	10	1	-	1	0.1	0.1
BAFFIN ISLAND TR.	OCT/80	22	80-T2-1 - 80-T2-22	50	50	-	50	0.1	0.1
80-6	NOV/80	4	80-6-18 - 80-6-21	10,50	1,50	-	1,50	0.1	0.1
LAKE MELVILLE TR.	FEB/MAR/81	13	81-T1-1 - 81-T1-13	1	1	1	1	1	1
81-1	JUL/81	1	81-1-1	10	10	10	10	10	1
ADMIRALTY INLET TR.	JUL/81	8	81-T2-2 - 81-T2-7	10	10	10	10	10	1
81-2	JUL/81	4	81-2-8 - 81-2-11	10	10	10	10	10	1
81-3	JUL/81	0	-	-	-	-	-	-	-
81-4	AUG/81	0	-	-	-	-	-	-	-
81-5	AUG/81	0	-	-	-	-	-	-	-
81-6	SEP/81	4	81-6-1 - 81-6-4	10,50	10	10	10	10	1
81-7	SEP/OCT/81	3	81-7-5 - 81-7-7	10	10	10	10	10	1
81-8	OCT/81	2	81-8-8 - 81-8-11	10	10	10	10	10	1
81-9	OCT/NOV/81	19	81-9-12 - 81-9-30	10,50,500	10,50,500	10	10	10	1,10
81-10	NOV/81	20	81-10-31- 81-10-49	10,50	10,50	10	10	10	1

* DATA SAMPLED IN "PEAK MODE"

TABLE 3
STATUS OF DATA COLLECTION ON PROPULSIVE PERFORMANCE

Prior to October 1980, most of the propulsion system data was recorded at relatively low sampling rates (1 and 0.1 samples/sec.). Higher sampling rates were employed during the last voyage of 1980 and the Arctic voyages in 1981. During these periods, most of the propulsion sensors were sampled at 10 samples per second. In several occasions, sampling rates up to 500 samples/sec. have been applied to the propeller shaft torque and thrust channels. The shaft r.p.m. data was only recorded during the Lake Melville and Admiralty Inlet trials and the 1981 season voyages.

During the Lake Melville trial, a separate, temporary analogue recording system was set up to record the propulsion system performance on analogue data tapes. The digital outputs of the propulsion system sensors were therefore only recorded by the computer at low sampling rates in order to maximize the data sampling capacity for hull structural strain measurements.

3.0 DATA REDUCTION

3.1 Methodology

The purpose of the data reduction in the present study is to extract information on ice induced effects on the ship's propulsion system and to present the data in a reduced and meaningful form which may be suitable for use in the design, operation and regulation development for ice transitting vessels. The tasks of the data extraction and manipulation required, generally fall into the following four areas:

- Identify events of ice/propeller interaction from the tape records;
- Identify ships operating and environment conditions from all records available;
- Data validation and categorization;
- Statistical analysis

Because of the large volume of data collected during the 1979-1980 period, and the requirement of detailed identification of various ships and ice parameters, the work of the data reduction has been performed with the aid of computers using an integrated computer program package developed for this project.

The tapes have been processed by a CDC Cyber 750 mainframe computer at the Canadian Cybernet Centre, Toronto, and the output transferred through a data communication link to the MSL in-house HP model 9816 computer for subsequent manipulation and analysis. This arrangement combines the benefit of the high efficiency of a mainframe computer and the cost effective and graphics capability of a desk-top computer.

A flow diagram outlining the procedure of data reduction and analysis is depicted in Figure 2.

The variation of the record of propeller shaft torque and thrust have been used as the triggers to recognize events of ice/propeller interaction.

A two-step approach has been adopted to search and read the data of ice/propeller interaction events from the magnetic tapes. Firstly, the tape has been scanned quickly by monitoring a small number of essential propulsion performance data channels (shaft torque, thrust, r.p.m. and ship Doppler speed log) and the mean, maximum and minimum values of those channel data are extracted at 30 second intervals. Figure 3 illustrates the spectra of shaft torque and thrust obtained from the tape scan. As can be seen in the figure, several events, large and abrupt changes of shaft torque and thrust excursion characteristics, are observed during the period shown. These events provide signatures of interaction between the propeller and ice.

After having recognized the occurrence of ice events from the first scanning of the tapes, the portion of the tape record containing data of interest is read again in order to extract the actual record of the

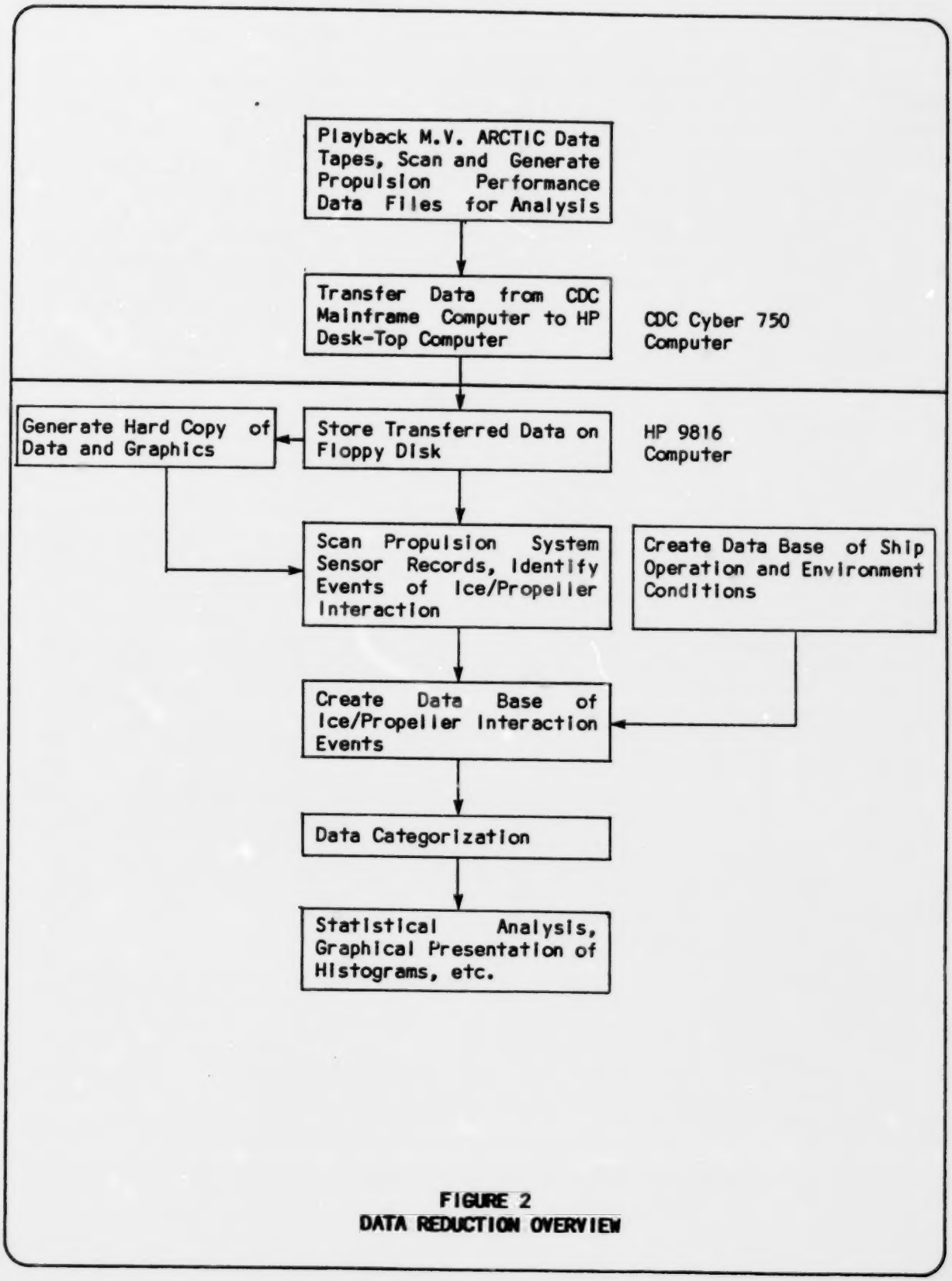
Playback M.V. ARCTIC Data Tapes, Scan and Generate Propulsion Performance Data Files for Analysis
Transfer Data from CDC Mainframe Computer to HP Desk-Top Computer
CDC Cyber 750 Computer
Generate Hard Copy of Data and Graphics
Store Transferred Data on Floppy Disk
HP 9816 Computer
Scan Propulsion System Sensor Records, Identify Events of Ice/Propeller Interaction
Create Data Base of Ship Operation and Environment Conditions
Create Data Base of Ice/Propeller Interaction Events
Data Categorization
Statistical Analysis, Graphical Presentation of Histograms, etc.

FIGURE 2
DATA REDUCTION OVERVIEW

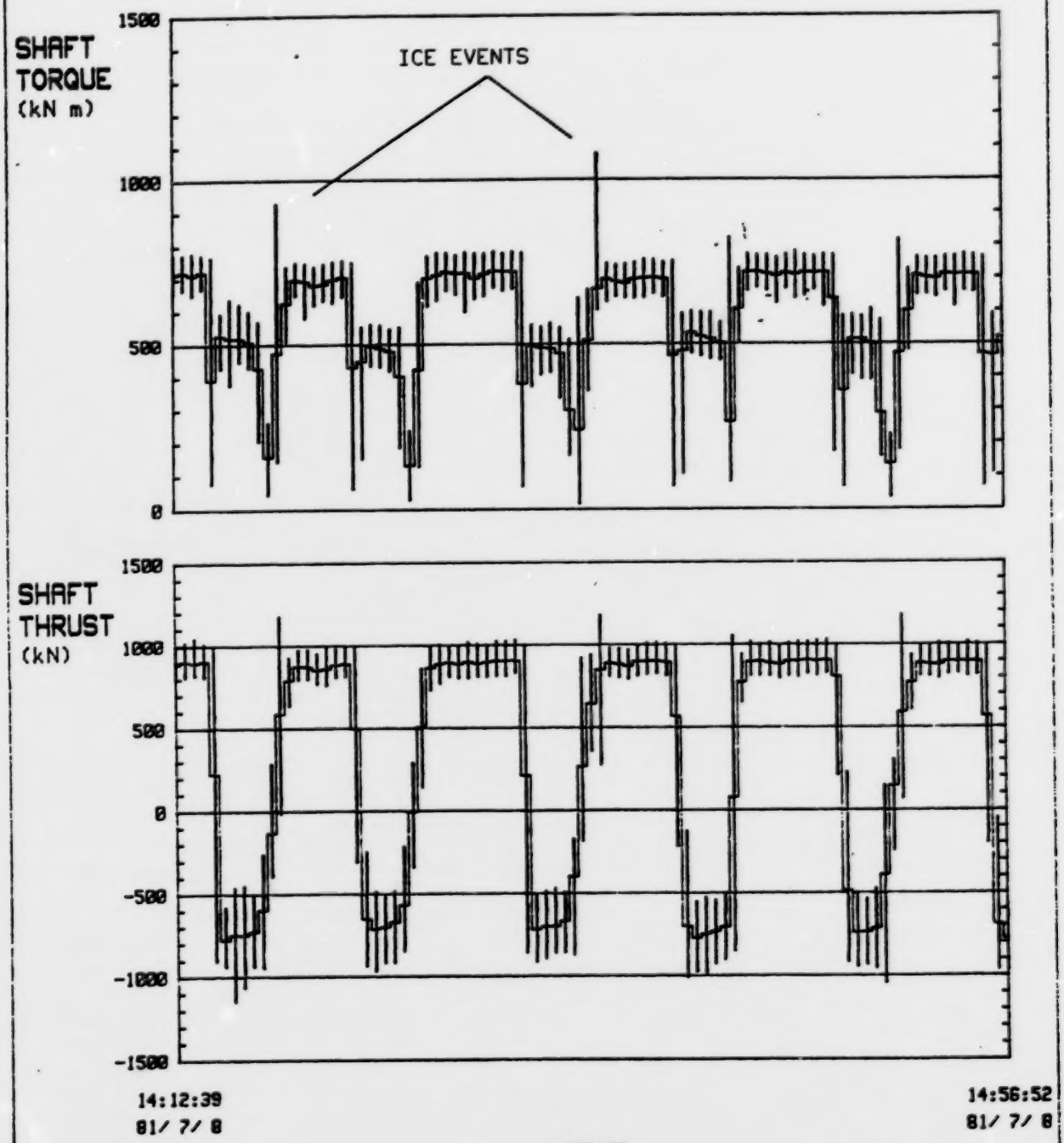

FIG. 3 SAMPLE OUTPUT FROM THE FIRST TAPE SCAN

propulsion system and other related channels for more detailed investigation. Usually, ten channels of record are extracted, including shaft torque, thrust, propeller pitch command and response, shaft r.p.m., ship speed, fuel rack, propeller pitch differential pressure and rudder angle and torque measurements. Figure 4 illustrates an example output of six propulsion channels obtained from the second tape reading. The output data provide not only detailed information of the response characteristics of each propulsion system parameter measured, but also confirmation of the ice/propeller event recognized by the 30 second interval spectra (Figure 3). The 30 second interval, selected by the capacity of data storage and transfer of the computer system, is justified by the observation that the duration of interaction event is normally in the order of one second or less and that the frequency of occurrence is low.

The computer programs used for the task of data reduction are of three types:

- Data tape playback program
- Asynchronous terminal emulator program
- Data manipulation and statistical analysis programs

From modification of the previous versions available, a new version of data tape playback program has been developed for use in the present work. The playback program presently developed, enables efficient data retrieval of selected channels from the raw data tapes. The data tapes were recorded in the format of 800 BPI (Bytes per inch), odd parity, 9 track and NRZI (Non-return-to-zero inverted). The present version maximizes the utilization of the random access capability the computer system provides. The output of this program, after execution, is stored in the disk memory of the mainframe computer. The output can be either in the form of statistical data of a few channels as used in the first scanning, or in the form of detailed time-history records as required by the second scanning on selective data records.

In addition, the playback program converts the digitized record of each sensor signal output into engineering unit using a set of conversion equations. Appendix 1 summarizes the conversion equations used for the propulsion system sensors and other related channels. The conversion factors shown vary in different voyage seasons or dedicated ice trial periods resulted from recalibration or readjustment of the data acquisition systems.

The data file generated by the playback program is then transferred to the MSL in-house HP 9816 desk-top computer using an asynchronous terminal emulator program available from Hewlett Packard Co. This program enables the HP 9816 computer to emulate the input/output features of the CDC mainframe and to function effectively in transferring ASCII data files to and from the remote computer through a modem and communication system. The data, after being transferred to the HP computer, is immediately stored on the computer's floppy disk for subsequent analysis.

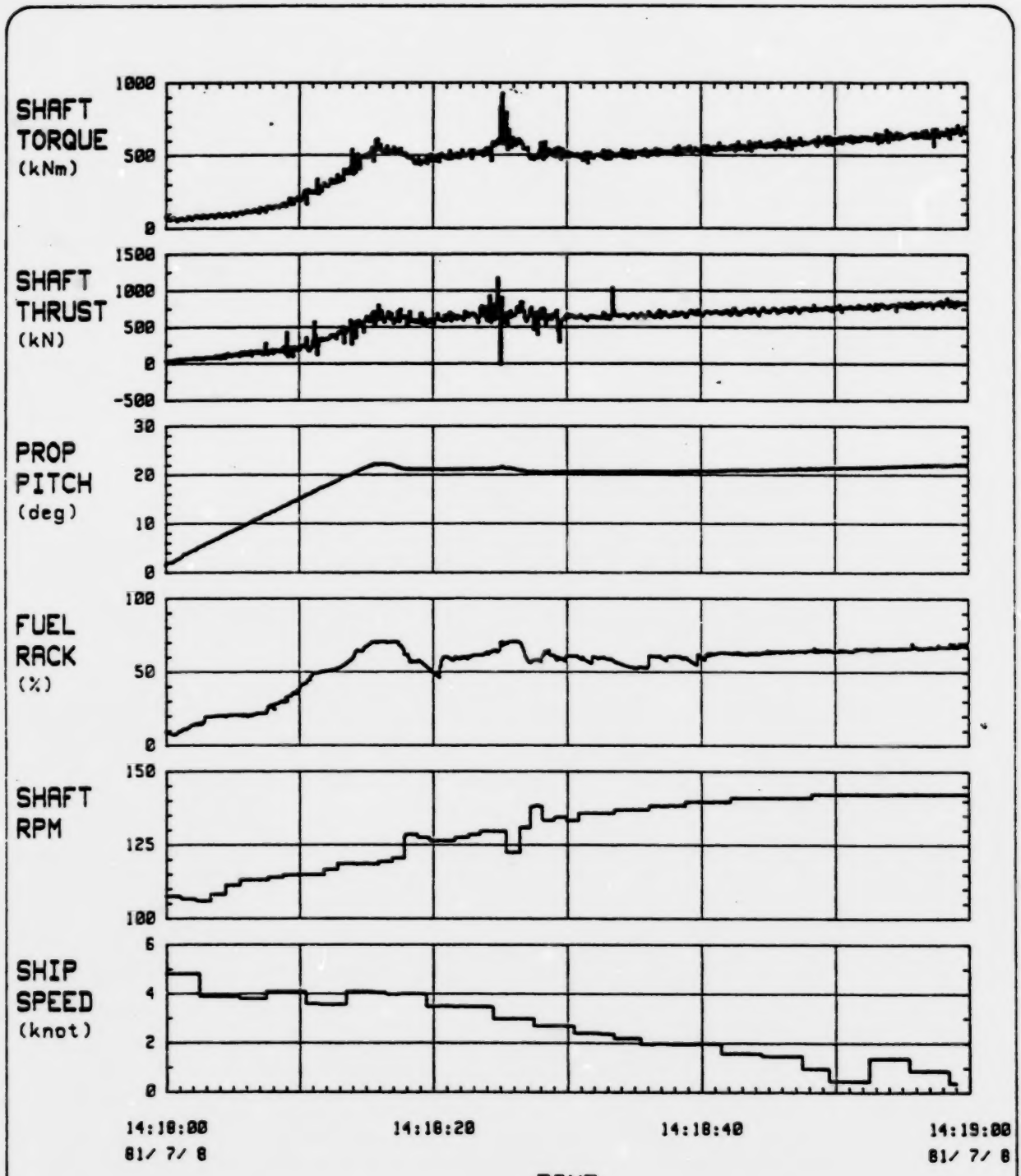

FIG. 4 SAMPLE OUTPUT FROM THE SECOND TAPE SCAN

A series of computer program has been developed with the HP computer to manipulate and analyze the data being transferred from the M.V. ARCTIC raw data tapes. The main functions of these programs are:

1) To identify the ice/propeller interaction events by examination of the variation of the recorded shaft thrust and torque excursion.
2) To create a data base of ice/propeller interaction event with detailed information of the ship and environment conditions.
3) To perform statistical analysis for various data categories.

The program package also has the capability to produce hard copy of the original or reduced data in tabulated or graphical form.

The data base created, contains the following information for each ice/propeller event identified:

- date and time
- ship location
- transit mode
- channel condition
- peak and mean shaft torque
- peak and mean shaft thrust
- mean shaft horsepower
- mean shaft r.p.m.
- mean ship speed
- thickness and concentration of first-year ice
- thickness and concentration of old ice
- ice ridging condition
- data category
- data storage identification (tape/file I.D., etc.)

The data collected is assembled into various categories according to the conditions of ship operation and environment. Details of the data categories used are given in the following section.

3.2 Data Category

To facilitate analysis of ice ingestion effects on the performance of the vessel's propulsion system, the data collected is assembled into categories defined by the operating conditions of the vessel and the ice environment circumstances. The data categories presently applied consist of:

1. Open Water
   1.1 Smooth Sea State
   1.2 Rough Sea State
2. Continuous Icebreaking
   2.1 Level Homogeneous Ice
   2.2 Uniform Mixed Ice
   2.3 Broken Channel
3. Ramming
   3.1 Level Ice
   3.2 Ridges

The open water categories provide a bench-mark for normal operating conditions of the ship's machinery, gear train, shafting and propeller. Since the sea state was not precisely documented in the reports related to the data acquisition programs or in the ship's bridge log, the open water condition is broken down into only two classes, smooth and rough sea states. The smooth sea state category is represented by the data collected while the ship was transitting in North Sea, Baffin Bay and Lancaster Sound area while the shipping route was ice free. The rough sea state category is represented by the data collected during trans-Atlantic crossings. It is expected that between June and November, the significant wave heights of Baffin Bay and North Sea are normally below 3 m, and those of Atlantic along the ARCTIC shipping route may frequently exceed 5 m.

Data of the ice/propeller interaction events identified has been grouped according to the icebreaking modes (continuous or ramming) and the ice conditions. As the ramming operation mode is usually required in penetrating ridges, only the level ice and broken channel are considered in the continuous icebreaking category. The level homogeneous ice category (2.1) is referred to as young and first-year ice without significant ridging or rubble features. The uniform mixed ice category (2.2) is assigned to the data collected when second-year or multi-year ice features were present along the ship route.

For the ramming operation mode, the category is subdivided into level ice (3.1) and ridges (3.2) groups. It should be noted that detailed information of ridge distribution and its geometry and strength properties is usually only available for the dedicated ice trials during which organized ramming tests were carried out. During the normal Arctic voyages however, records of ridge data is scanty and incomplete. In the present data classification, the ice condition is assumed to be "level" unless encountering of ice ridges was noted in the existing data collection records.

Because of the limited number of significant ice events recorded, ice concentration and other ship manoeuvring conditions have not been considered as major elements in the data category.

4.0 PRELIMINARY RESULTS AND CONCLUSIONS

4.1 Introduction

The data from which the analysis of the performance of the propulsion system will be carried out comprises:

- propeller shaft torque
- propeller shaft thrust
- propeller shaft r.p.m.
- propeller blade pitch
- engine fuel rack position
- ship speed
- propeller hydraulic position at differential oil pressure (total blade spindle torque)
- rudder angle
- rudder hydraulic ram differential oil pressure
- engine combinator command
- engine room vertical and transverse accelerations.

At this interim stage, selected examples of the first six items of the aforementioned parameters have been extracted from the records of the 1981 Arctic Date Collection season which was judged to be the best quality of the recordings.

Records have been selected for presentation in Appendix 4 of this report to show typical examples of ice interaction with the propulsion system in the various data categories. In order that a bench-mark can be established, two examples of the response of the ship's propulsion system when in open water have also been included. The data categories to be found in Appendix 4 are as follows:

a) open water, calm seas	Figure A4.1 - A4.7
b) open water, rough seas	Figure A4.8 - A4.14
c) continuous ice breaking, level homogenous ice	Figure A4.15 - A4.23
d) continuous ice breaking, uniform mixed ice	Figure A4.24 - A4.32
e) broken channel	Figure A4.33 - A4.43
f) ramming level ice	Figure A4.44 - A4.59
g) ramming ridges	Figure A4.60 - A4.68

In each of the categories, the data is presented in "real time" on a coarse time scale from which examples of the most significant events have been reconstructed on a short or fine time scale, see Figure 5 and 6. The mean torque for a typical block of data has been plotted against the peak torque to illustrate the magnitude of variation for different values of mean torque. Variation of shaft thrust has been similarly expressed over the same time scale as the torque. Typical examples of these plots are shown in Figures 7 and 8.

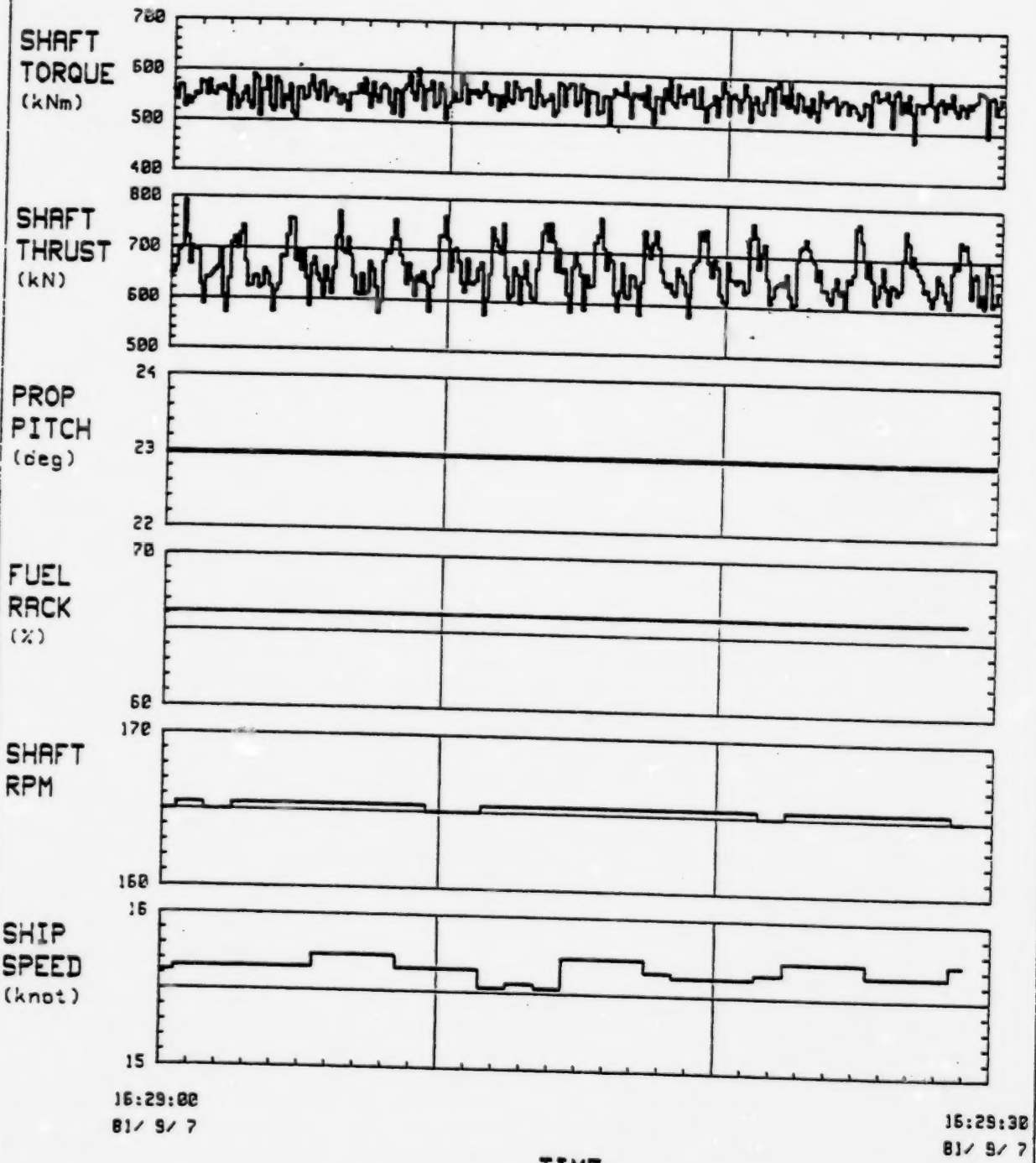

FIGURE 5 PROPULSIVE PERFORMANCE RECORD

(OPEN WATER, SMOOTH SEASTATE)

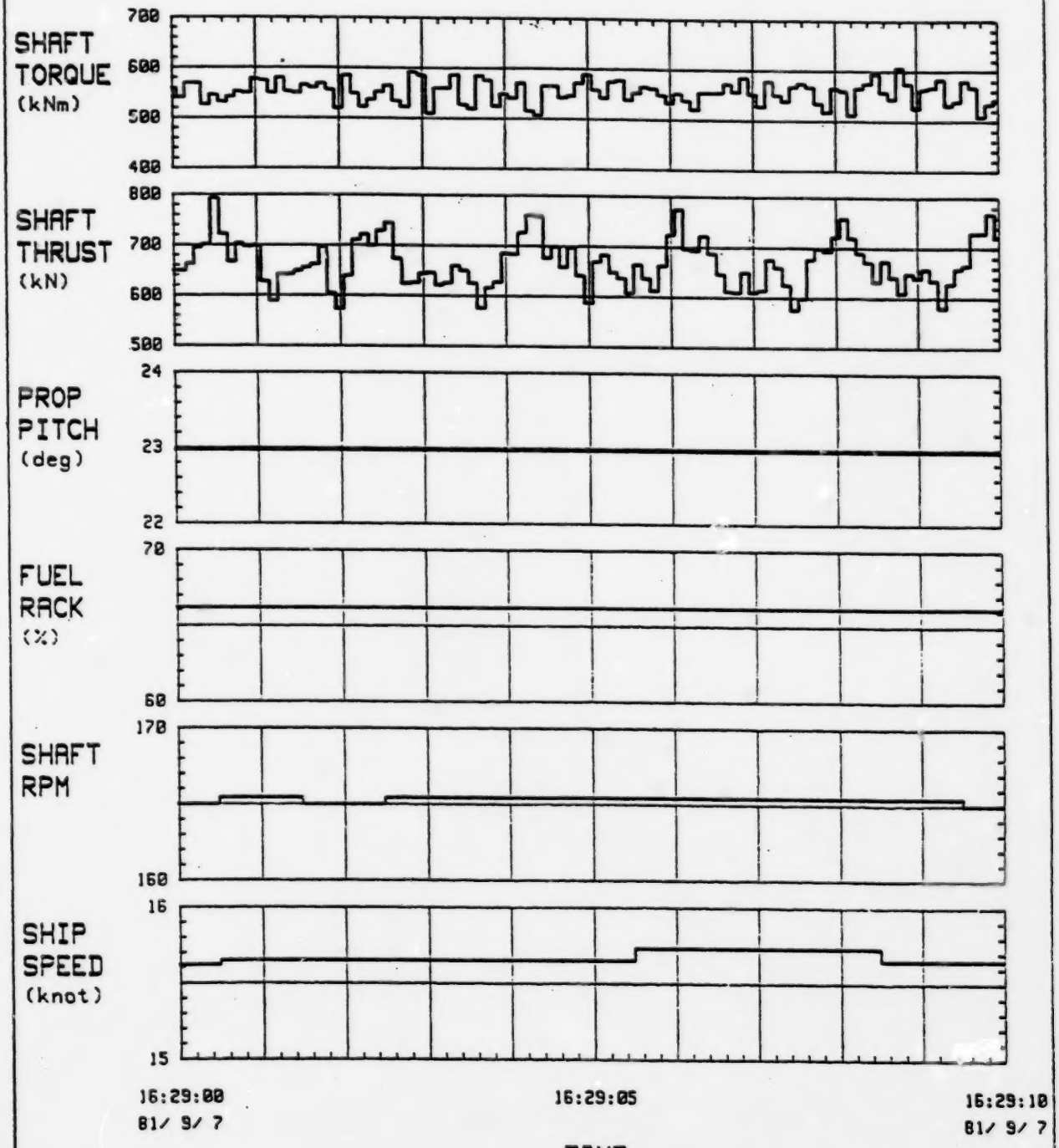

FIGURE 6 PROPULSIVE PERFORMANCE RECORD

(OPEN WATER, SMOOTH SEASTATE)

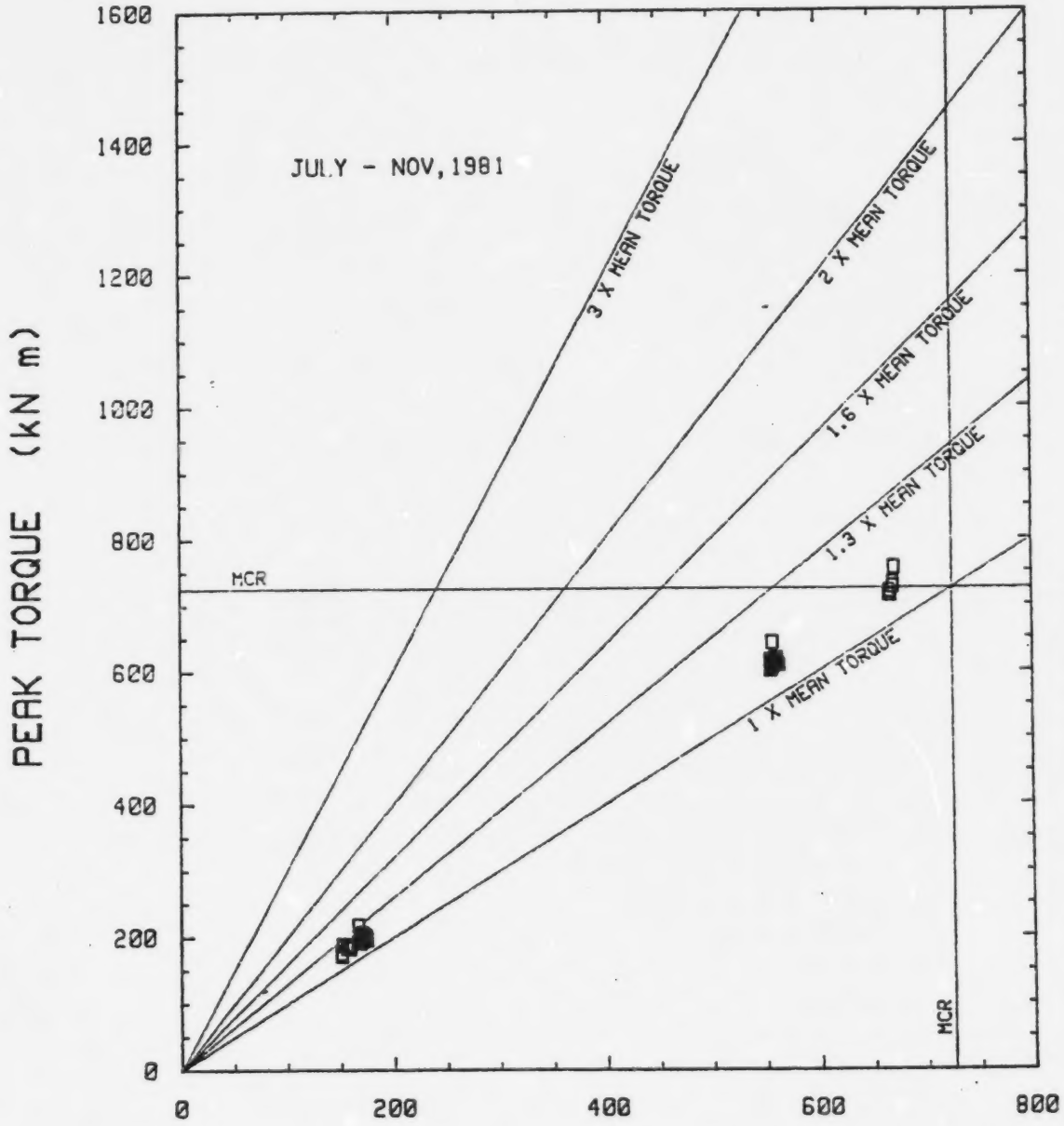

FIG. 7 SHAFT TORQUE EXCURSIONS IN OPEN WATER

(Category 1.1 : OPEN WATER, SMOOTH SEASTATE)

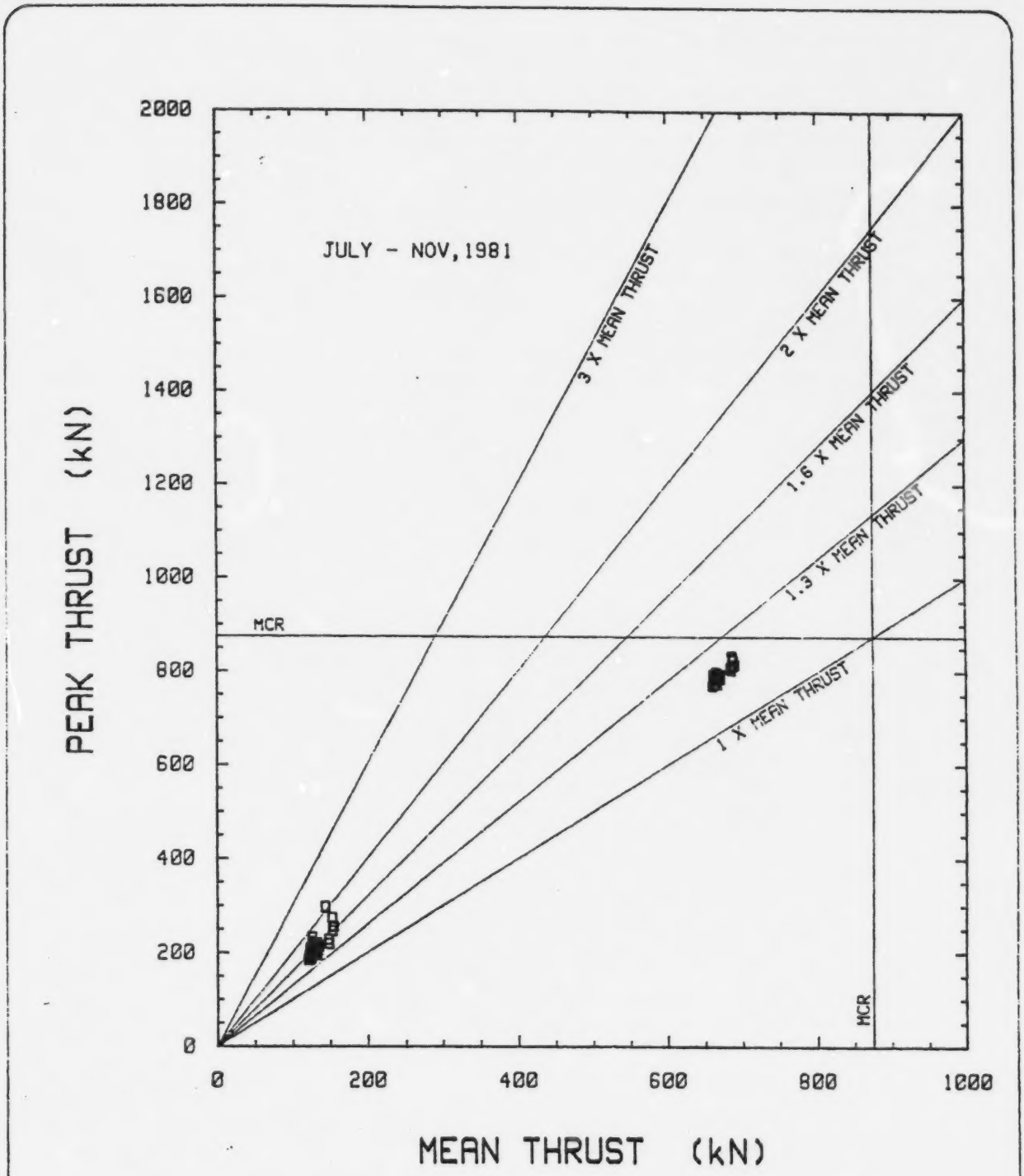

FIG. 8 SHAFT THRUST EXCURSIONS IN OPEN WATER

(Category 1.1 : OPEN WATER, SMOOTH SEASTATE)

In order to illustrate the magnitude of torque excursions and thrust from the mean values, the excursions, termed ice torque and ice thrust when operating in ice, have been plotted against a number of events (counts) over a selected period of time, see Figures 9 and 10. In this regard an event has been defined as a positive or negative variation of torque or thrust in excess of 30% of the mean value at the time.

4.2 Open Water Bench-Marks

Open water bench-marks have been established to assess the performance of the propulsion system when operating in ice covered waters as follows:

a) the open water signature of torque and thrust;
b) propeller shaft torsional and axial stress when operating at MCR (Maximum Continuous Rating) and normal open water power, i.e., 80 - 85% MCR.

The open water characteristic torque and thrust of the vessel at approximately 80% MCR are shown in Figures 5 and 6 for smooth water and Figures 11 and 12 for rough water. In both examples the torsional vibratory response is small representing ± 10 - 15% of the mean torque at a variety of frequenices. The low frequency component in Figure 11 is probably due to variation of propeller submergence due to wave and ship motions.

The thrust or the axial vibratory response of the shafting system in Figure 5 is approximately ± 14% of the mean thrust, principally at 0.5 hz., on which is superimposed the propeller blade passing frequency. It is believed possible that 0.5 hz. component may be a natural axial frequency of the shaft system. In the example shown in Figure 11, the vibratory component of thrust is approximately ± 15% of the mean thrust at propeller blade passing frequency.

The propeller and intermediate shaft torsional and axial stress when operating at engine MCR conditions has been calculated as follows:

100% MCR, 14,700 BHP, 143 r.p.m.

Torsional Stress (propeller shaft)	52 MPa
Torsional Stress (intermediate shaft)	76 MPa (rated torque 725 kN.m)
Axial Stress (intermediate shaft)	0.26 MPa (thrust 875 kN)

Open Water Engine Power 80 - 85% MCR, 11,820 - 12,550 BHP, 143 r.p.m.

Torsional Stress (propelle shaft)	42 - 44 MPa
Torsional Stress (intermediate shaft)	61 - 65 MPa
Axial Stress (intermediate shaft)	0.22 - 0.24 MPa

The fatigue strength of the shaft material, due to combined torsional and bending ranges from 102 MPa for pure bending to 151 MPa for pure torsion, see Figure 12. The fatigue strength due to axial loading is approximately 200 MPa. Therefore a factor of safety of 2 against failure of the shafting system due to torsional and bending fatigue, and a factor of 1,000 against failure due to axial fatigue, has been provided.

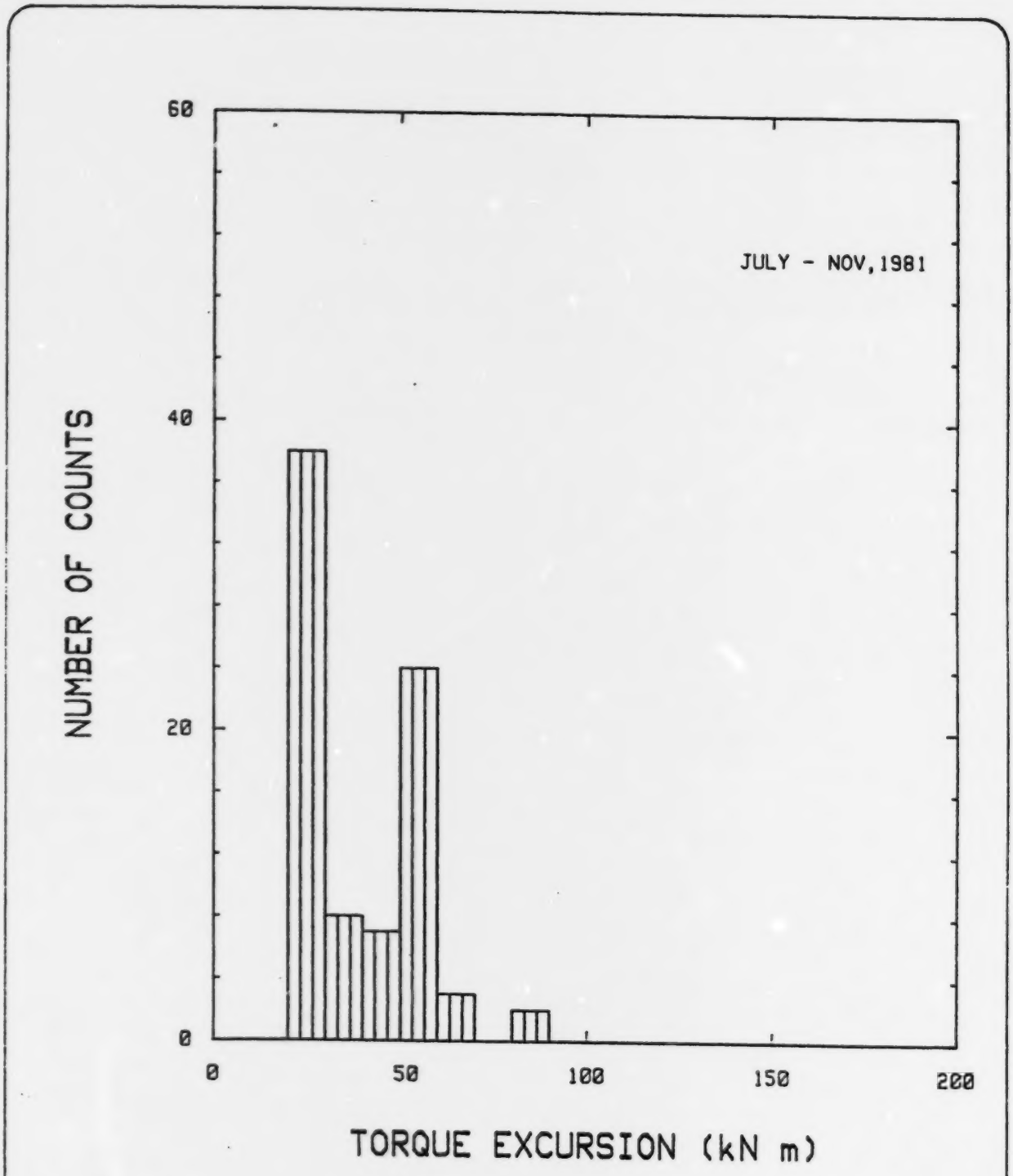

FIG. 9 DISTRIBUTION OF SHAFT TORQUE EXCURSIONS

(Category 1.1 : OPEN WATER, SMOOTH SEASTATE)

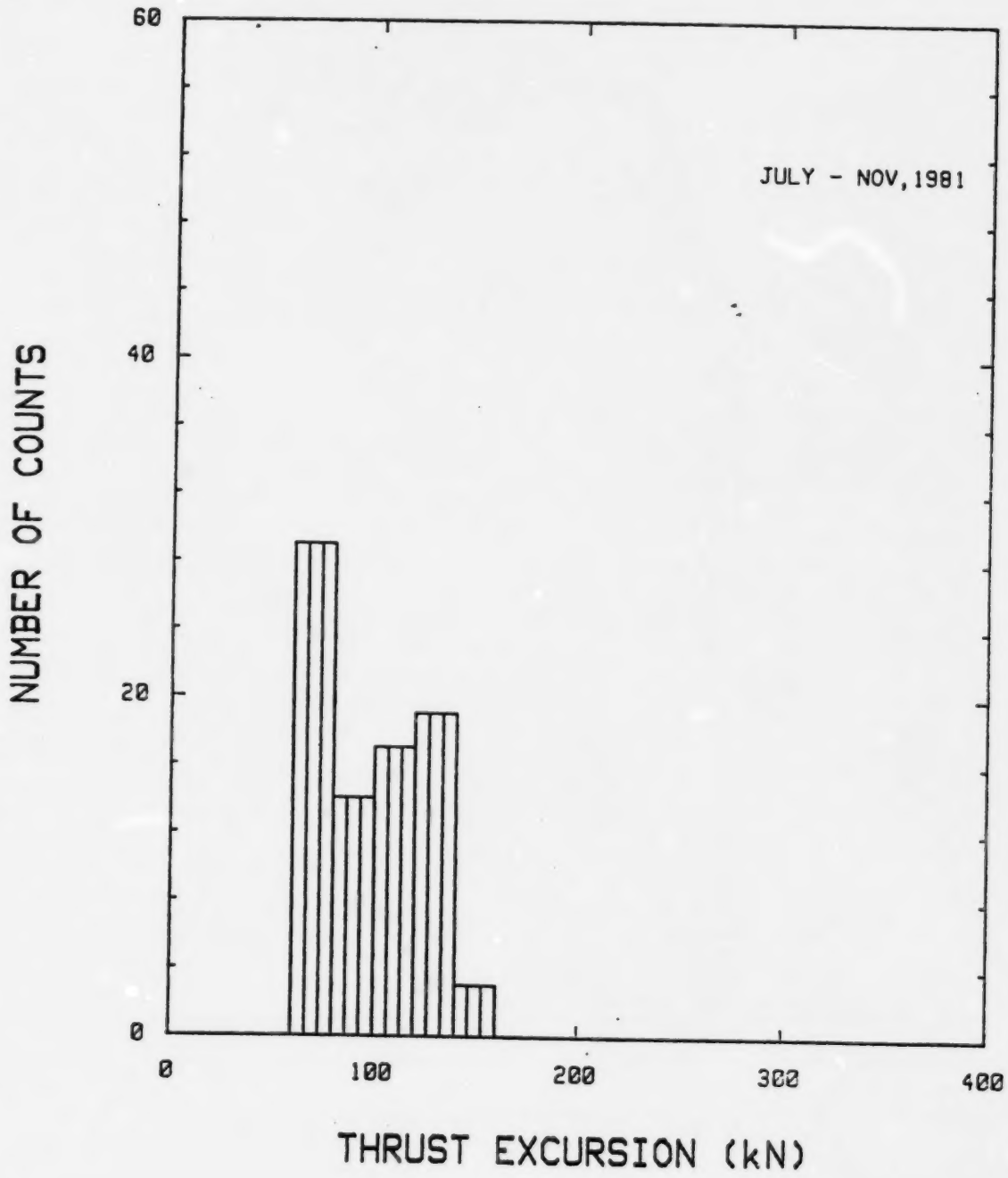

FIG. 10 DISTRIBUTION OF SHAFT THRUST EXCURSIONS

(Category 1.1 : OPEN WATER, SMOOTH SEASTATE)

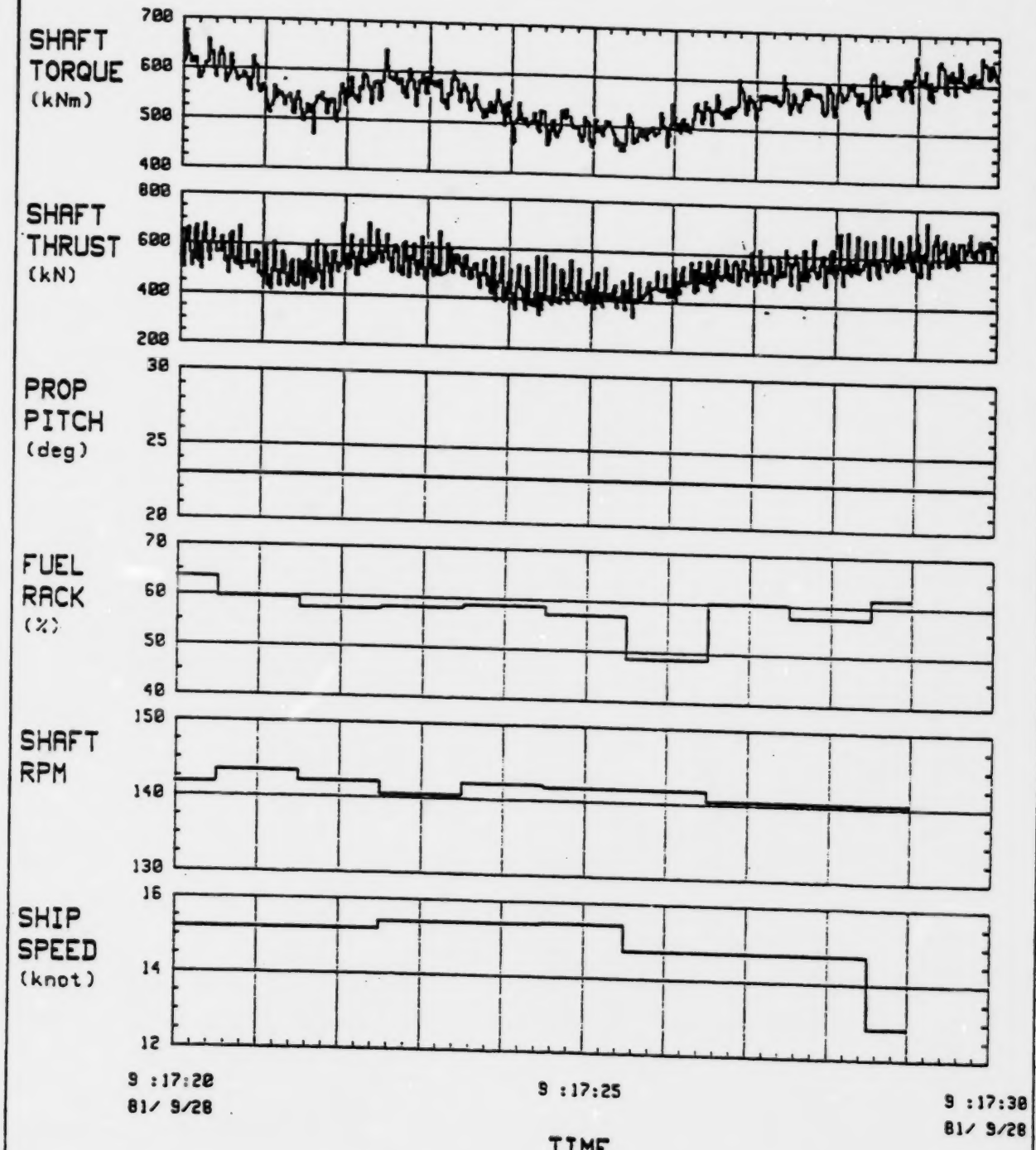

FIGURE 11 PROPULSIVE PERFORMANCE RECORD

(OPEN WATER, ROUGH SEASTATE)

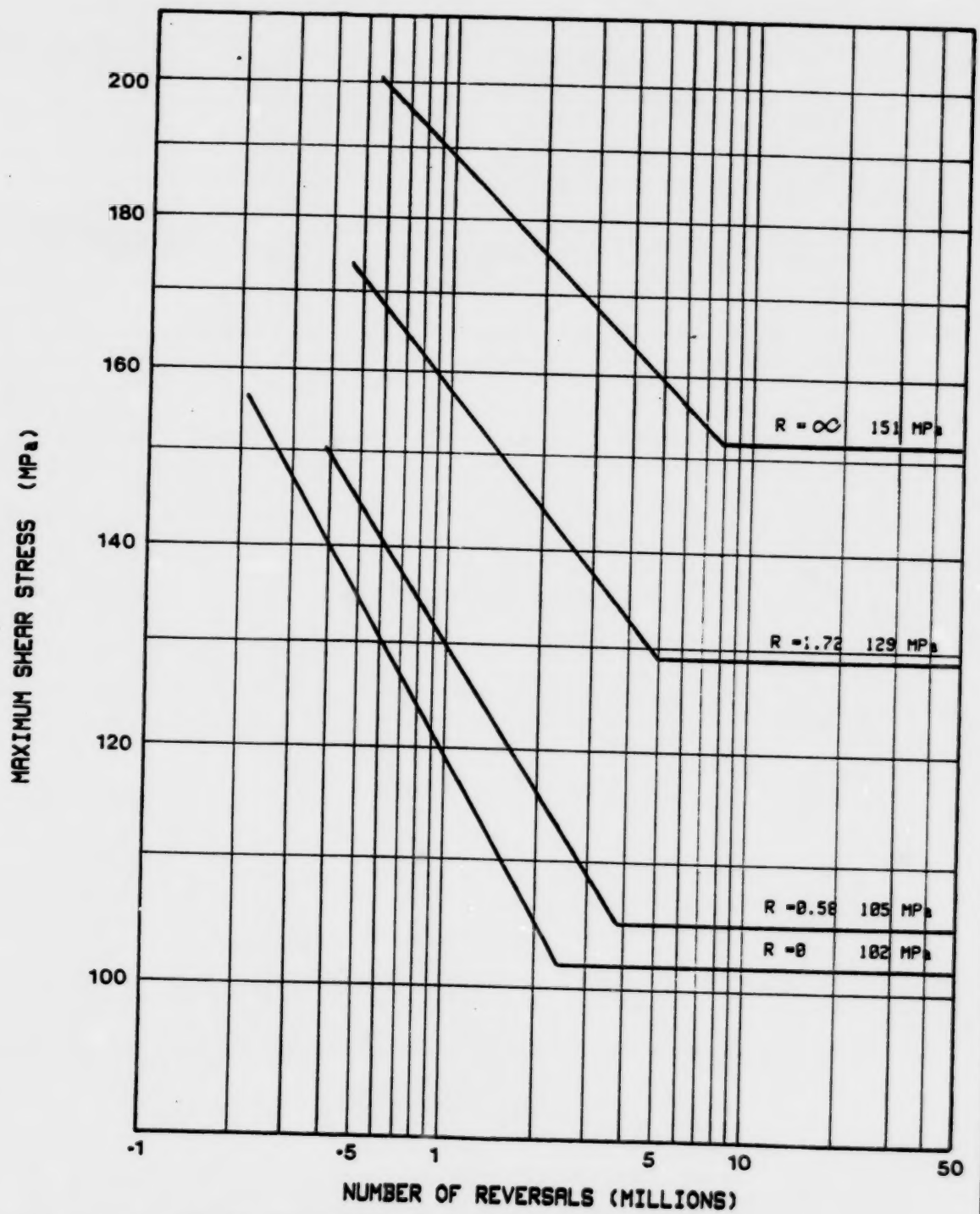

FIGURE 12 COMBINED BENDING AND TORSION FATIGUE CURVES

(R = APPLIED TORQUE / APPLIED BENDING MOMENT)

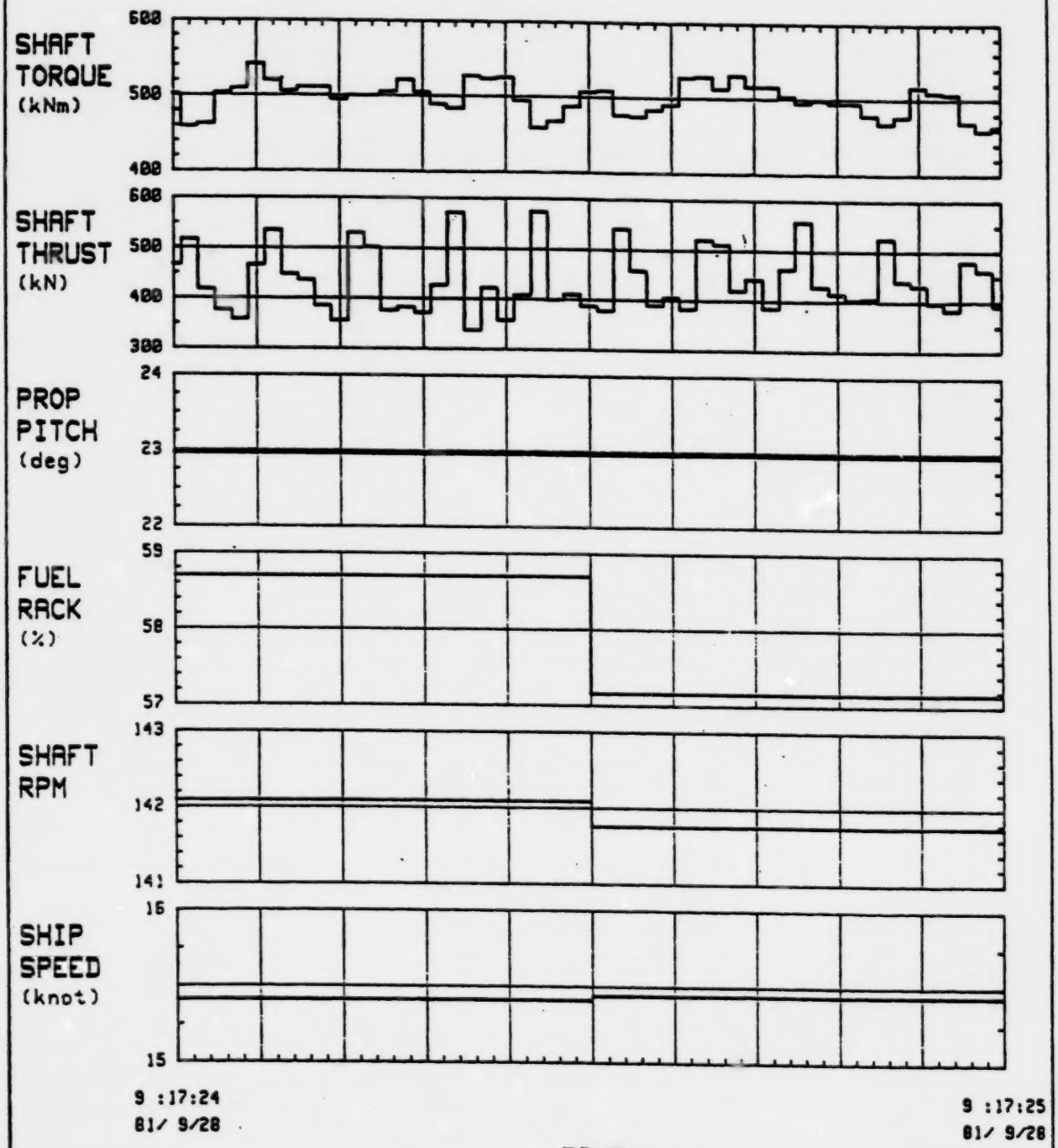

FIGURE 13 PROPULSIVE PERFORMANCE RECORD

(OPEN WATER, ROUGH SEASTATE)

The gearing fitted to the propulsion system is designed for continuous operation at 30% in excess of the maximum torque which can be generated by the primemover, i.e., 130% torque. In addition, the Classification Society requires that the gearing be capable of continuous operation at its designed load with 30% vibratory torque. Also coefficients for shock loading (C_o), life (C_l), safety (C_r), dynamic effects (C_v), load distribution (C_m), etc., are applied by the designer to the gears based upon judgement. The net effect of the application of these semi-empirical allowances will result in overall factors of safety for marine gears, based upon material properties (either fatigue or yield strength), in excess of 2 and sometimes as high as 4. Without a knowledge of the value of the various coefficients used in the design, it is not possible to comment upon the adequacy of the gearing as fitted. It would be expected that the overload factor (C_o) used in the gear design would not be less than 1.5 and by ignoring all other allowances this factor combined with the 30% overtorque capability will result in a gear design capable of operation up to 195% of rated torque. The further application of a typical factor of safety of 1.5 for a design rated according to fatigue strength will increase the overall factor of safety of the gear to approximately 3. (Ref. 3.).

4.3 Discussion and Conclusions

The ice interaction with the propulsion system via the propeller takes the form of torque and thrust excursions, often termed ice torque and ice thrust. These excursions sometimes are of a single contact type, as typified in Figure 14. This type of incident may be due to a single block of ice passing through the propeller and the size of the torque excursion is dependent, to a major extent, upon the inertia of the block.

The second form of propeller/ice interaction is shown by Figure 15. This type of response is of a multiple contact type which would be expected if a large block of ice entered the propeller aperture and was "milled". The size of the torque excursion in this type of incident would be strongly influenced by both the ice strength and by ice block inertia.

These two incidents also show the two different types of axial response to the shaft system. In the single impact event there was no distinct axial disturbance of the system recorded. This is reinforced by the incident shown in Figure 16. When multiple impacts take place, as during milling, the axial response to an increase in thrust is both positive and negative related to mean thrust.

Another type of incident is shown in Figure 17 and shows rapid reduction in thrust due to ice ingestion by the propeller. This type of reaction is believed to be due to momentary masking of the propeller aperture of the ice until cleared by the propeller blades. As the torque excursion is relatively small in this incident, this event may be due to a quantity of small ice pieces entering the nozzle or a large piece of rotten ice was destroyed by a single impact of a blade.

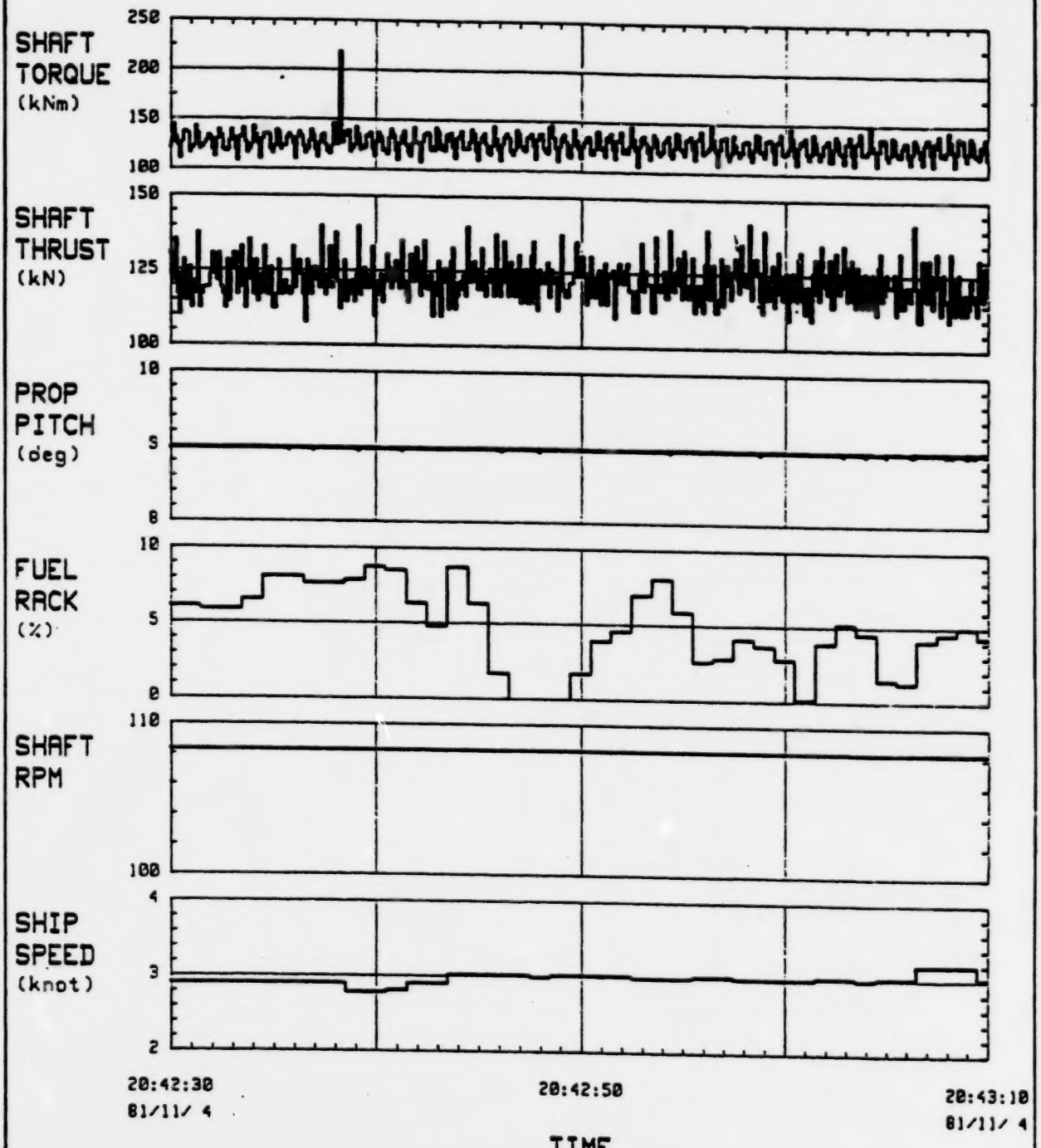

FIGURE 14 PROPULSIVE PERFORMANCE RECORD

(CONTINUOUS ICE BREAKING, LEVEL HOMOGENEOUS ICE)

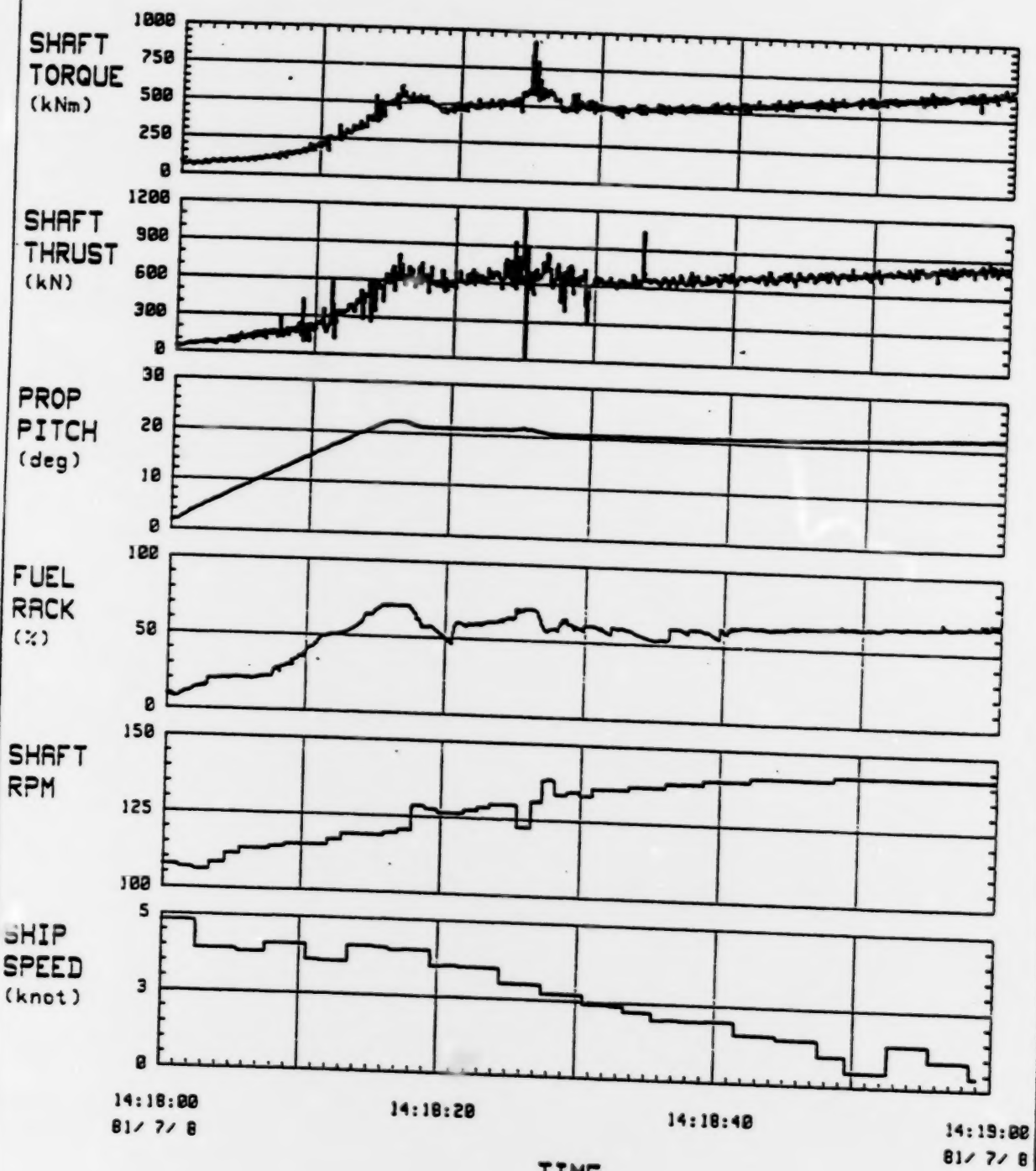

FIGURE 15 PROPULSIVE PERFORMANCE RECORD

(RAMMING, LEVEL ICE)

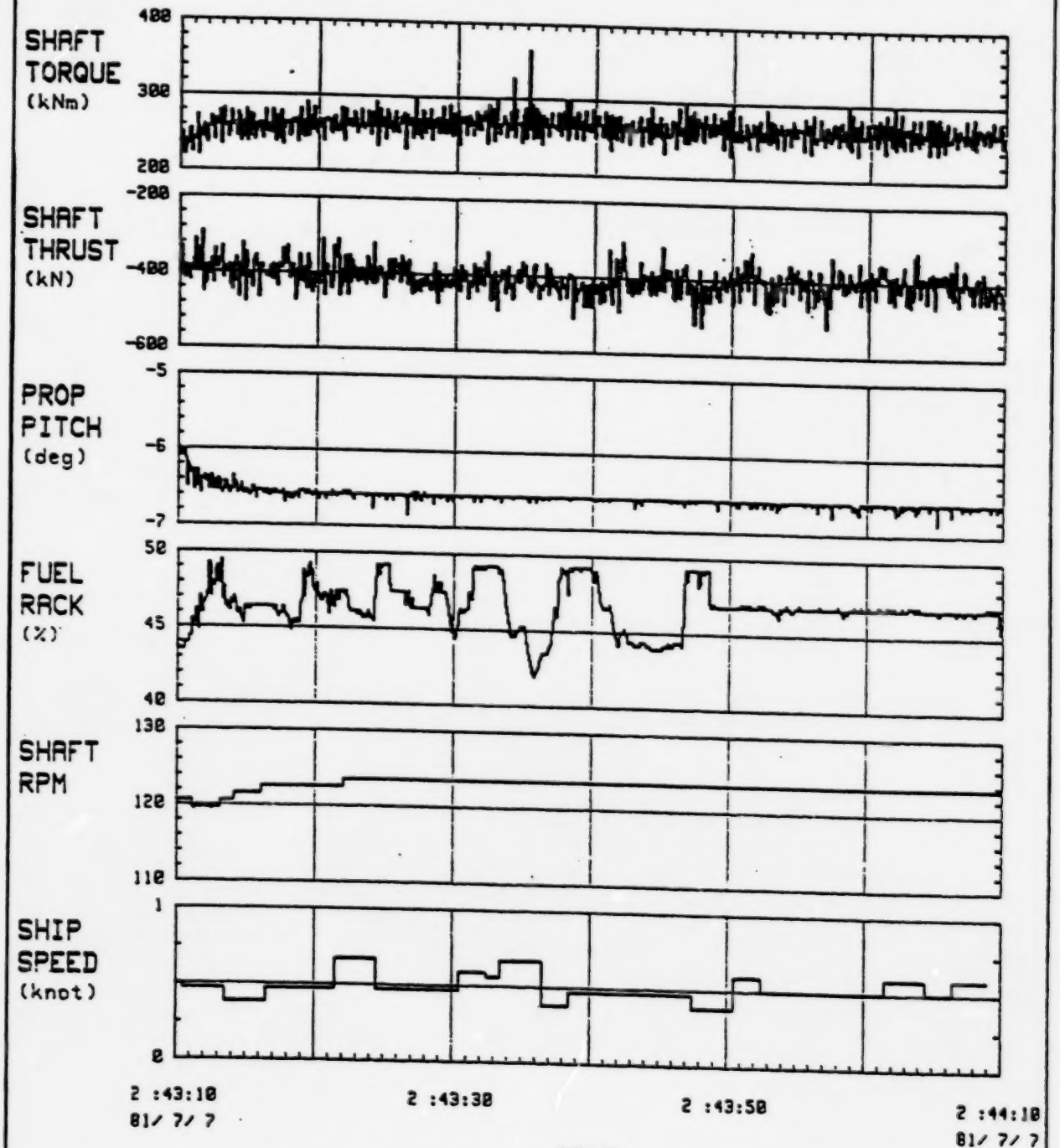

FIGURE 16 PROPULSIVE PERFORMANCE RECORD

(RAMMING, RIDGES)

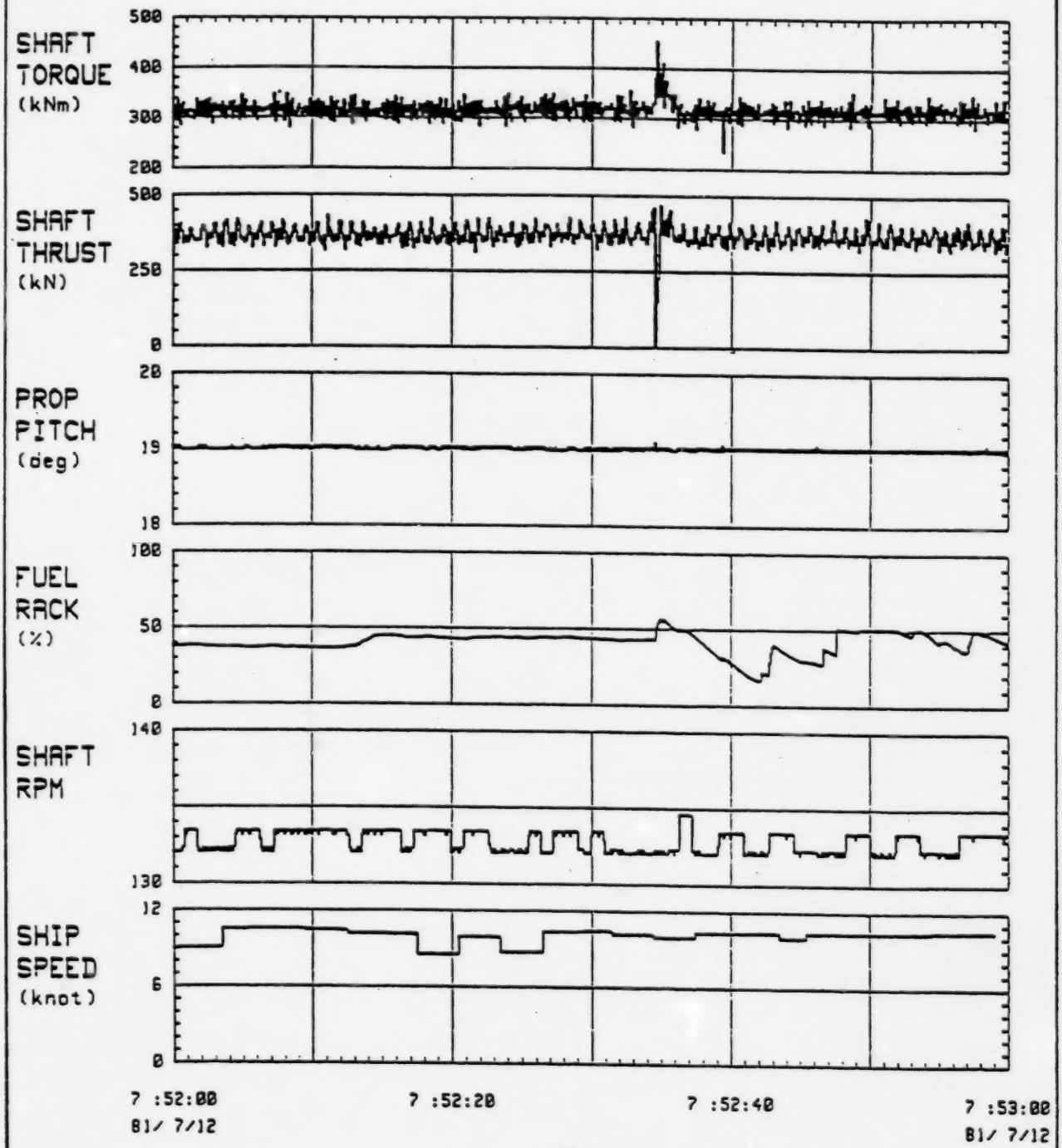

FIGURE 17 PROPULSIVE PERFORMANCE RECORD

(BROKEN CHANNEL)

All the figures shown in this interim report are based on the conversion equations (Table A1.1) provided in the previously published reports (Ref. 4 - 9) regarding the data acquisition program of the M.V. ARCTIC. The accuracy of the data deduced from the tape records will be examined and the data validation will be discussed in the final report of this study.

The graphical data displayed in the appendix is shown separately for each data category as discussed in Section 3.2. Means are being considered whereby the results of each category can be brought together into a single visual representation for easier interpretation and comparison.

Figure 18 summarizes all the ice induced shaft torque excursion data extracted from the July - November 1981 record. The upper limits of the measured peak and mean torques for various ice transiting modes are indicated in the figure. The results show that occurrences of large magnitude of peak torque due to ice/propeller interactions are more frequent in ramming mode than in continuous ice transit. The peak/mean torque ratios measured are generally below 2 while the ship was operating at high power range. Incidents of ice induced peak torques greater than 200% of the corresponding mean torque occurred most often when operating at low power. However, there is no strong evidence that the peak/mean torque ratio could be preferrably higher in any particular ship/ice interaction mode.

The extracted shaft torque excursion data for all ice/propeller events is displayed in Figure 19. It appears that the reading of the thrust meter installed in the M.V. ARCTIC was limited to a maximum of about 1,177 kN (120 Mp). Consequently, any incidents of peak thrust exceeding this level could not be correctly recorded. From the trend of the peak and mean thrust relationships shown in Figure 19, it is possible that the maximum peak thrust due to ice interaction is about 200 - 250 MCR when the ship is operating at near full power. The observed peak/mean thrust ratio is generally below 2.5 except in low power operation.

From the data scanned to date, the peak events of thrust and torque excursions have occurred when ramming level ice, see Appendix 4, Figures A4.44 to A4.60. These figures show the peak incident in 33 hours of recordings which caused a torque excursion of 1,275 kN.m, 1.7 x rated intermediate shaft torque. These torques in terms of intermediate shaft torsional stress are 129 MPa and, 88 MPa in terms of propeller shaft torsional stress.

Figure 12 shows the limiting fatigue stress, based upon 10^7 cycles, to be 151 MPa for the intermediate shaft, and between 151 MPa and 102 MPa for the propeller shaft. The peak measured stresses correspond to approximately 85% of the fatigue stress and are not therefore considered to be harmful either from considerations of fatigue or yield.

With respect to this type of loading on the gears, which are believed to be rated for shock loads of up to twice designed torque, no damage is expected to result.

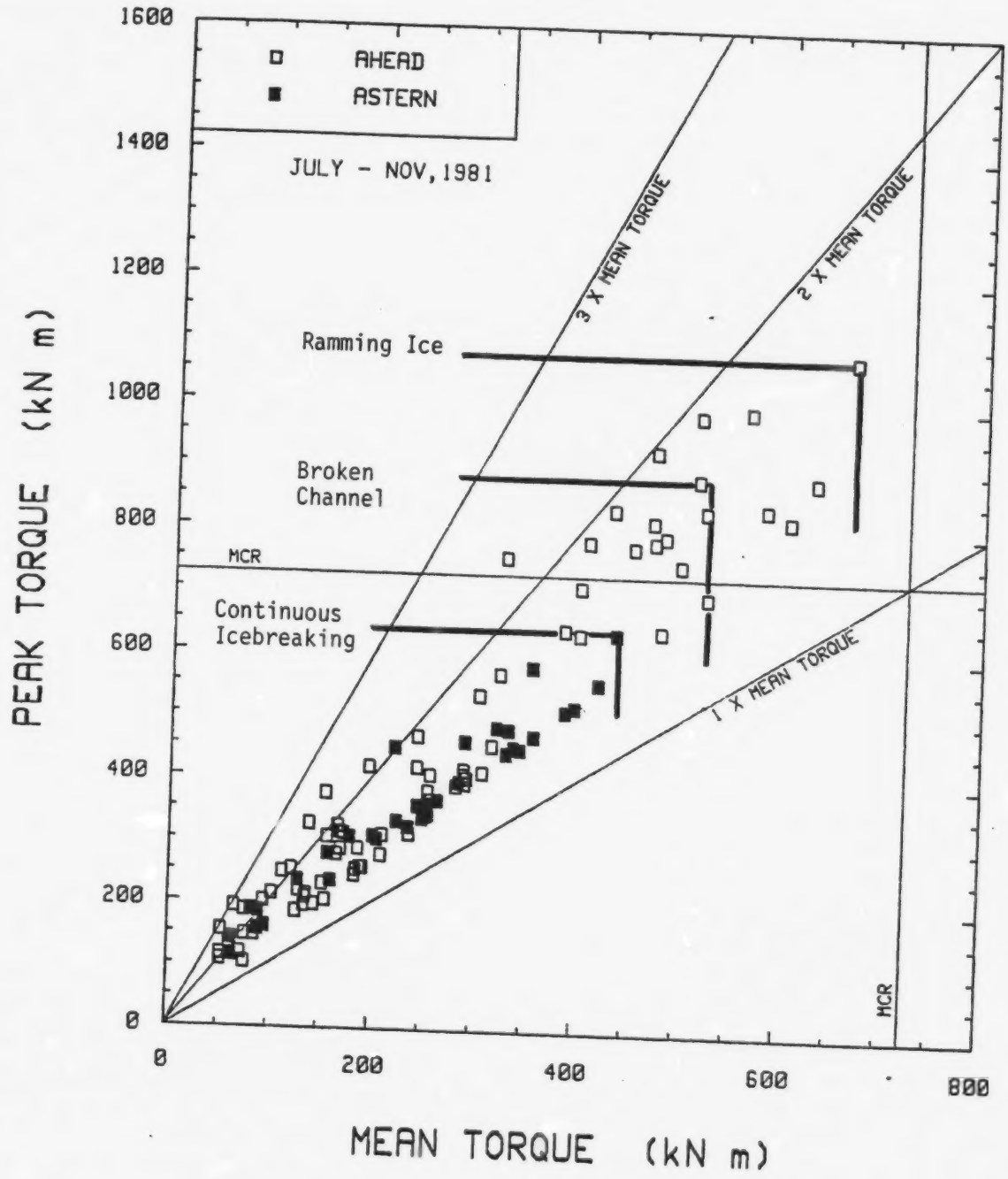

FIG. 18 MEASURED ICE-INDUCED SHAFT TORQUE EXCURSIONS

(All Ice Transit Conditions)

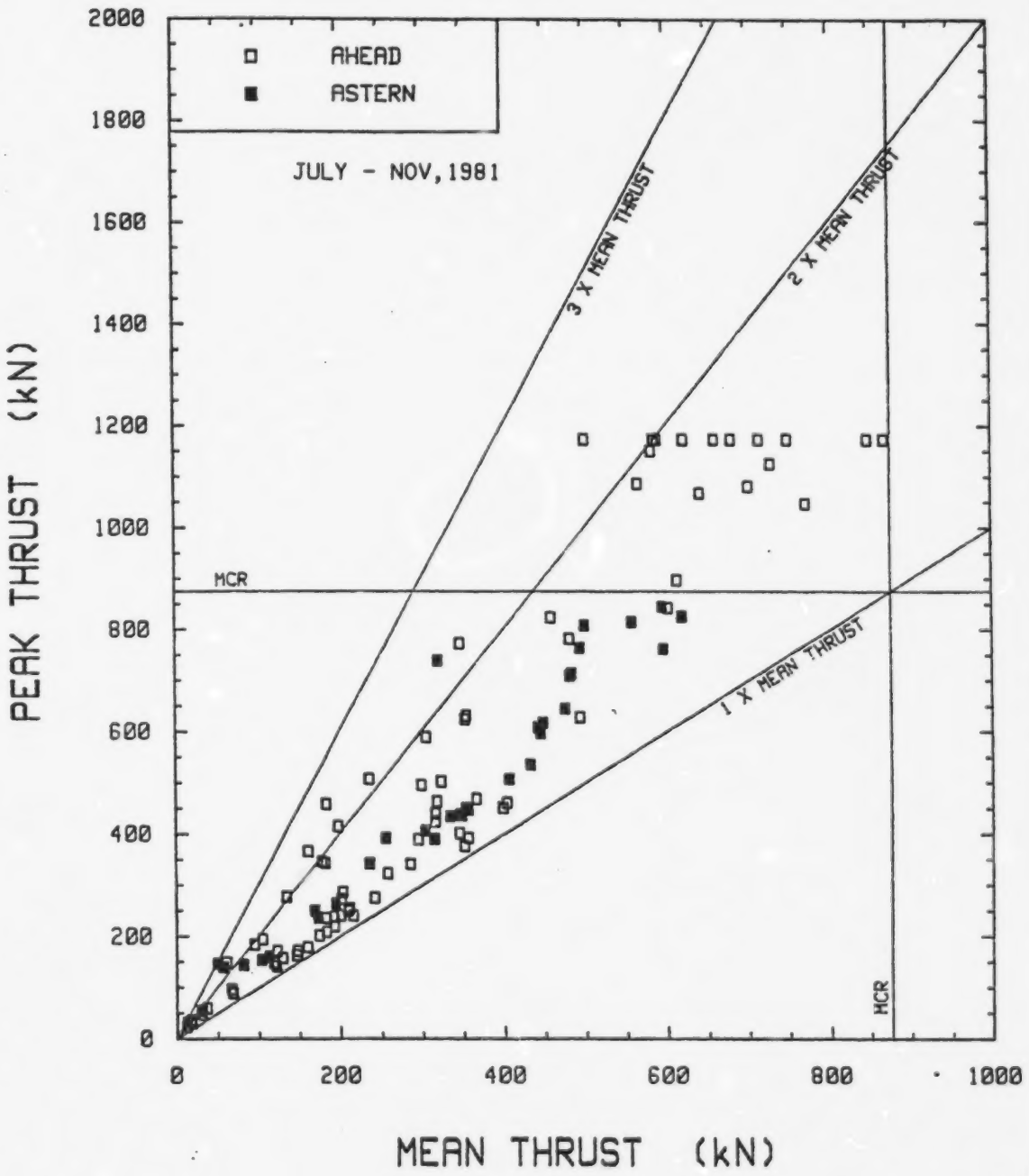

FIG. 19 MEASURED ICE-INDUCED SHAFT THRUST EXCURSIONS

(All Ice Transit Conditions)

All other incidents of propeller/ice interaction which are shown in the figures in Appendix 4 have resulted in peak torques below the values quoted in the preceeding paragraph. As the stresses are smaller than the limiting fatigue stress they are judged to be inconsequential.

REFERENCES

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2. "Data Collection System Onboard the Ice-Strengthened Cargo Vessel M.V. ARCTIC For Evaluation of Ship Performance in Ice", SNAME Sixth Ship Technology and Research (STAR) Symposium, German, J.G., Stirling, J., Benjamin, A., Timonen, P., and Hearnshaw, J.D., June 17-19, 1981.

3. "Gear Handbook", McGraw-Hill Company, Dudley, D.W.

4. "M.V. ARCTIC Scientific Evaluation Project Data Collection Activity (1979-1980 Season)", Vol. I & II, German & Milne (TP2627).

5. "M.V. ARCTIC Data Collection and Instrumentation", Vol. I & II, Fenco (TP3202).

6. "M.V. ARCTIC Data Collection and Instrumentation", Vol. I & II, Fenco (TP3632).

7. "M.V. ARCTIC Data Collection and Instrumentation", Vol. I & II, Arctec Canada Ltd. (TP3634).

8. "M.V. ARCTIC - Special Report on Lake Melville Probe", Melville Shipping Ltd. (TP3809).

9. "M.V. ARCTIC Master Data Package 1979-1981 Seasons", German & Milne (TP3821E).

APPENDIX 1

CONVERSION EQUATIONS USED IN DATA REDUCTION

(Table A1.1 - Conversion Equations used in Data Reduction for Channels of Propulsion System and Other Sensors)

TABLE A1.1

CONVERSION EQUATIONS USED IN DATA REDUCTION FOR

CHANNELS OF PROPULSION SYSTEM AND OTHER SENSORS

PARAMETER MEASURED	CHANNEL NO.	CONVERSION EQUATION *	UNIT	RECORDING ** PERIOD				
				A	B	C	D	E
Shaft Thrust	198	2.4N-1155.7	kN	X	X			
		2.298N-1176.8	kN			X	X	X
Fuel Rack Position	199	0.2201N-9.97	%	X	X	X	X	X
Rudder Angle (Response)	200	0.0781N-40	deg	X		X	X	X
		0.071N-36			X			
Propeller Pitch (Response)	201	0.01953N-10	deg	X		X	X	
		0.0468N-22			X			
		0.0371N-15						X
Propeller Pitch O.D. Box Diff. Pressure	203	0.00135N	MPa	X	X	X	X	
		0.0009766N	MPa					X
Shaft Torque	208	0.974N-320	kN.m	X				
		0.92N-320	kN.m		X			
		Various	kN.m			X		
		1.762N-201.7	kN.m				X	
		1.803N-185	kN.m					X
Shaft r.p.m.	211	1203.6/[0.01963N+0.09]	rpm				X	
		61440/[N+18.4]						X

TABLE A1.1 (Continued)

CONVERSION EQUATIONS USED IN DATA REDUCTION FOR

CHANNELS OF PROPULSION SYSTEM AND OTHER SENSORS

PARAMETER MEASURED	CHANNEL NO.	CONVERSION EQUATION *	UNIT	RECORDING ** PERIOD				
				A	B	C	D	E
Surge (aft)	212	0.048N-24.5	$m.s^{-2}$			X	X	X
Sway (aft)	213	0.048N-24.5	$m.s^{-2}$			X	X	X
Heave (aft)	214	0.048N-24.5	$m.s^{-2}$			X	X	X
Ship Speed	236	0.019N+0.86 0.0293N	knot knot	X	X	X	X	X
Engine r.p.m.	241	0.55N-4	rpm	X				
Combinator	244	0.01953N-10		X	X	X	X	X
Rudder Diff. Pressure	202	0.0336N 0.02394N	MPa MPa	X	X	X	X	X
Rudder Torque	196	2.2133N-1132	kN.m					X

* N = digitized value of sensor output signal

** recording period = (A) July 1979
(B) Sept. - Nov. 1979
(C) 1980
(D) Feb. - Mar. 1981
(E) June - Nov. 1981

APPENDIX 2

1981 ARCTIC OPERATION SEASON DATA RECORD

(Table A2.1 - M.V. ARCTIC Tape Records Collected During the Period of July - November 1981)

TABLE A2.1 : M.V. ARCTIC TAPE RECORDS COLLECTED DURING THE PERIOD OF JULY - NOVEMBER 1981

TAPE/FILE	DATE	TIME from	TIME to	TRANSIT MODE	CHANNEL CONDITION	1-yr ICE m	1-yr ICE tenth	OLD ICE m	OLD ICE tenth	RIDGE DEPTH m	LOCATION
81-01-01.01	81-07-05	17:28:15	20:51:38	CONTINUOUS	NEW	1.5	1	---	--	---	LANCASTER SOUND
81-T2-02.01	81-07-07	02:13:12	05:12:00	RAMMING	NEW	1.5	10	---	--	2.3	ADMIRALTY INLET
81-T2-03.01	81-07-07	13:35:52	15:41:49	RAMMING	NEW	1.6	10	---	--	4.9	ADMIRALTY INLET
81-T2-03.02	81-07-07	15:44:32	15:48:29	RAMMING	NEW	1.5	10	---	--	4.9	ADMIRALTY INLET
81-T2-03.03	81-07-07	15:52:52	15:53:49	RAMMING	NEW	1.6	10	---	--	4.9	ADMIRALTY INLET
81-T2-04.01	81-07-07	17:54:32	17:57:22	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-T2-04.02	81-07-07	18:03:32	18:36:01	RAMMING	NEW	1.6	10	---	--	---	ADMIRALTY INLET
81-T2-04.03	81-07-07	18:36:35	18:52:15	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-T2-04.04	81-07-07	18:53:00	19:29:59	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-T2-05.01	81-07-08	14:12:39	14:56:52	RAMMING	NEW	1.6	10	---	--	---	ADMIRALTY INLET
81-T2-05.02	81-07-08	15:26:57	15:27:26	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-T2-05.03	81-07-08	15:35:52	15:37:11	RAMMING	NEW	1.6	10	---	--	---	ADMIRALTY INLET
81-T2-05.04	81-07-08	15:39:52	15:40:55	RAMMING	NEW	1.6	10	---	--	---	ADMIRALTY INLET
81-T2-05.05	81-07-08	15:41:52	15:42:32	RAMMING	NEW	1.6	10	---	--	---	ADMIRALTY INLET
81-T2-05.06	81-07-08	15:49:01	15:53:01	RAMMING	NEW	1.6	10	---	--	1.9	ADMIRALTY INLET
81-T2-05.07	81-07-08	15:54:52	15:55:42	RAMMING	NEW	1.6	10	---	--	1.9	ADMIRALTY INLET
81-T2-05.08	81-07-08	15:57:59	16:08:12	RAMMING	NEW	1.6	10	---	--	1.9	ADMIRALTY INLET
81-T2-06.01	81-07-08	19:16:09	19:16:37	RAMMING	NEW	1.8	10	---	--	1.9	ADMIRALTY INLET
81-T2-06.02	81-07-08	19:16:46	19:24:15	RAMMING	NEW	1.8	10	---	--	1.9	ADMIRALTY INLET
81-T2-06.03	81-07-08	19:24:39	19:27:42	RAMMING	NEW	1.8	10	---	--	1.9	ADMIRALTY INLET
81-T2-06.04	81-07-08	19:27:48	19:30:17	RAMMING	NEW	1.8	10	---	--	1.9	ADMIRALTY INLET
81-T2-06.05	81-07-08	19:30:23	19:30:34	RAMMING	NEW	1.8	10	---	--	---	ADMIRALTY INLET
81-T2-06.06	81-07-08	19:30:40	19:31:10	RAMMING	NEW	1.8	10	---	--	---	ADMIRALTY INLET
81-T2-06.07	81-07-08	19:31:16	19:37:34	RAMMING	NEW	1.8	10	---	--	---	ADMIRALTY INLET
81-T2-06.08	81-07-08	19:39:31	19:50:19	RAMMING	NEW	1.8	10	---	--	---	ADMIRALTY INLET
81-T2-06.09	81-07-08	19:50:26	20:13:59	RAMMING	NEW	1.2	10	---	--	---	ADMIRALTY INLET
81-T2-06.10	81-07-08	20:16:41	20:22:23	RAMMING	NEW	1.2	10	---	--	---	ADMIRALTY INLET
81-T2-06.11	81-07-08	20:25:12	20:32:02	RAMMING	NEW	1.2	10	---	--	---	ADMIRALTY INLET
81-T2-06.12	81-07-08	20:35:33	20:36:27	RAMMING	NEW	1.2	10	---	--	---	ADMIRALTY INLET
81-T2-06.13	81-07-08	20:36:37	20:38:34	RAMMING	NEW	1.2	10	---	--	---	ADMIRALTY INLET
81-T2-07.01	81-07-08	22:36:13	22:36:42	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-T2-07.02	81-07-08	22:36:52	22:36:53	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-T2-07.03	81-07-08	22:37:01	22:37:02	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-T2-07.04	81-07-08	22:37:12	22:37:58	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-T2-07.05	81-07-08	22:38:33	22:43:53	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-T2-07.06	81-07-08	22:44:54	22:45:37	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-T2-07.07	81-07-08	22:46:31	22:47:00	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-T2-07.08	81-07-08	22:49:52	22:51:42	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-T2-07.09	81-07-08	22:53:46	22:53:58	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-T2-07.10	81-07-08	22:56:21	23:12:01	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-T2-07.11	81-07-08	23:13:32	23:18:56	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-T2-07.12	81-07-08	23:20:25	23:20:31	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-T2-07.13	81-07-08	23:23:31	23:23:44	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-T2-07.14	81-07-08	23:25:54	23:40:02	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-T2-07.15	81-07-08	23:42:00	23:43:39	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-T2-07.16	81-07-08	23:47:13	23:47:42	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET

TABLE A2.1 (CONT): M.V. ARCTIC TAPE RECORDS COLLECTED DURING THE PERIOD OF JULY - NOVEMBER 1981

TAPE/FILE	DATE	TIME from	TIME to	TRANSIT MODE	CHANNEL CONDITION	1-yr ICE m	1-yr ICE tenth	OLD ICE m	OLD ICE tenth	RIDGE DEPTH m	LOCATION
81-T2-07.17	81-07-08	23:51:38	23:54:47	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-T2-07.18	81-07-08	23:55:44	00:06:21	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-02-08.01	81-07-09	00:18:44	00:29:02	RAMMING	NEW	1.5	10	---	--	---	ADMIRALTY INLET
81-02-08.02	81-07-09	00:30:18	01:24:00	CONTINUOUS	BROKEN	1.5	10	---	--	---	ADMIRALTY INLET
81-02-09.01	81-07-12	06:21:52	06:23:28	CONTINUOUS	BROKEN	1.5	10	---	--	---	ADMIRALTY INLET
81-02-09.02	81-07-12	07:14:32	07:15:07	CONTINUOUS	BROKEN	1.5	10	---	--	---	ADMIRALTY INLET
81-02-09.03	81-07-12	07:15:49	07:18:40	CONTINUOUS	BROKEN	1.5	10	---	--	---	ADMIRALTY INLET
81-02-09.04	81-07-12	07:19:14	07:20:55	CONTINUOUS	BROKEN	1.5	10	---	--	---	ADMIRALTY INLET
81-02-09.05	81-07-12	07:21:57	07:32:11	CONTINUOUS	BROKEN	1.5	10	---	--	---	ADMIRALTY INLET
81-02-09.06	81-07-12	07:33:52	08:09:51	CONTINUOUS	BROKEN	1.5	10	---	--	---	ADMIRALTY INLET
81-02-10.01	81-07-12	08:27:48	09:15:40	CONTINUOUS	BROKEN	1.5	10	---	--	---	ADMIRALTY INLET
81-06-01.01	81-09-06	17:21:12	17:31:10	CONTINUOUS	OPEN W	---	--	---	--	---	NANISIVIK DOCK
81-06-01.02	81-09-06	17:48:32	17:52:19	CONTINUOUS	OPEN W	---	--	---	--	---	NANISIVIK DOCK
81-06-01.03	81-09-06	20:53:45	20:54:14	CONTINUOUS	OPEN W	---	--	---	--	---	LANCASTER SOUND
81-06-02.01	81-09-07	16:28:10	16:42:23	CONTINUOUS	OPEN W	---	--	---	--	---	BAFFIN BAY
81-06-02.02	81-09-07	19:36:38	19:52:05	CONTINUOUS	OPEN W	---	--	---	--	---	BAFFIN BAY
81-06-02.03	81-09-08	09:57:25	10:07:44	CONTINUOUS	OPEN W	---	--	---	--	---	BAFFIN BAY
81-06-02.04	81-09-08	14:21:51	14:28:45	CONTINUOUS	OPEN W	---	--	---	--	---	BAFFIN BAY
81-06-02.05	81-09-08	16:08:25	16:08:54	CONTINUOUS	OPEN W	---	--	---	--	---	BAFFIN BAY
81-06-02.06	81-09-08	17:47:34	17:58:32	CONTINUOUS	OPEN W	---	--	---	--	---	BAFFIN BAY
81-06-02.07	81-09-08	20:36:01	20:49:50	CONTINUOUS	OPEN W	---	--	---	--	---	BAFFIN BAY
81-06-03.01	81-09-09	17:13:55	17:14:33	CONTINUOUS	OPEN W	---	--	---	--	---	ATLANTIC OCEAN
81-06-03.02	81-09-09	17:40:03	18:19:46	CONTINUOUS	OPEN W	---	--	---	--	---	ATLANTIC OCEAN
81-07-05.01	81-09-26	04:17:55	07:06:05	CONTINUOUS	OPEN W	---	--	---	--	---	NORTH SEA
81-07-06.01	81-09-28	06:39:12	06:52:42	CONTINUOUS	OPEN W	---	--	---	--	---	ATLANTIC OCEAN
81-07-06.02	81-09-28	07:26:33	07:40:02	CONTINUOUS	OPEN W	---	--	---	--	---	ATLANTIC OCEAN
81-07-06.03	81-09-28	09:17:18	09:30:48	CONTINUOUS	OPEN W	---	--	---	--	---	ATLANTIC OCEAN
81-07-06.04	81-09-28	09:34:21	09:35:19	CONTINUOUS	OPEN W	---	--	---	--	---	ATLANTIC OCEAN
81-09-13.01	81-11-03	13:26:52	13:31:35	CONTINUOUS	NEW	0.2	10	---	--	---	BAFFIN BAY
81-09-13.02	81-11-03	15:06:32	15:20:15	CONTINUOUS	NEW	0.2	10	---	--	---	BAFFIN BAY
81-09-13.03	81-11-03	15:22:12	15:43:14	CONTINUOUS	NEW	0.2	10	---	--	---	BAFFIN BAY
81-09-13.04	81-11-03	16:07:48	16:08:03	CONTINUOUS	NEW	0.1	7	---	--	---	BAFFIN BAY
81-09-13.05	81-11-03	16:10:22	16:26:52	CONTINUOUS	NEW	0.4	8	---	--	---	BAFFIN BAY
81-09-13.06	81-11-03	16:56:32	17:49:53	CONTINUOUS	NEW	0.5	8	---	--	---	BAFFIN BAY
81-09-13.07	81-11-03	18:40:32	19:18:03	CONTINUOUS	NEW	0.2	7	---	--	---	BAFFIN BAY
81-09-14.01	81-11-03	19:54:32	19:57:29	CONTINUOUS	NEW	0.2	7	---	--	---	BAFFIN BAY
81-09-14.02	81-11-03	19:58:41	20:33:04	CONTINUOUS	NEW	0.2	10	---	--	---	BAFFIN BAY
81-09-14.03	81-11-03	20:34:32	22:08:13	CONTINUOUS	NEW	0.2	10	---	--	---	BAFFIN BAY
81-09-15.01	81-11-04	15:43:16	15:42:31	CONTINUOUS	NEW	0.3	2	---	--	---	BYLOT ISLAND
81-09-15.02	81-11-04	17:37:06	17:37:11	CONTINUOUS	NEW	0.3	2	---	--	---	BYLOT ISLAND
81-09-15.04	81-11-04	18:07:00	18:45:01	CONTINUOUS	NEW	0.3	2	---	--	---	BYLOT ISLAND
81-09-16.01	81-11-04	18:56:13	19:08:44	CONTINUOUS	NEW	0.3	1	---	--	---	BYLOT ISLAND
81-09-16.02	81-11-04	20:31:35	20:49:49	CONTINUOUS	NEW	0.3	1	---	--	---	BYLOT ISLAND
81-09-16.03	81-11-04	20:50:52	21:32:21	CONTINUOUS	NEW	0.3	6	1.2	3	---	BYLOT ISLAND
81-09-17.01	81-11-04	21:57:59	23:28:51	CONTINUOUS	NEW	0.3	6	1.2	3	---	BYLOT ISLAND
81-09-17.02	81-11-05	13:12:28	13:23:41	CONTINUOUS	NEW	0.3	6	1.2	3	---	BYLOT ISLAND

TABLE A2.1 (CONT): M.V. ARCTIC TAPE RECORDS COLLECTED DURING THE PERIOD OF JULY - NOVEMBER 1981

TAPE/FILE	DATE	TIME from	TIME to	TRANSIT MODE	CHANNEL CONDITION	1-yr ICE m	1-yr ICE tenth	OLD ICE m	OLD ICE tenth	RIDGE DEPTH m	LOCATION
81-09-19.01	81-11-05	19:28:17	20:31:20	CONTINUOUS	NEW	0.3	10	---	--	---	LANCASTER SOUND
81-09-19.02	81-11-05	20:34:12	20:38:28	CONTINUOUS	NEW	0.3	10	---	--	---	LANCASTER SOUND
81-09-19.03	81-11-06	18:05:12	18:08:14	RAMMING	NEW	0.3	10	---	--	---	LANCASTER SOUND
81-09-19.04	81-11-06	18:08:21	18:08:31	RAMMING	NEW	0.3	10	---	--	---	LANCASTER SOUND
81-09-19.05	81-11-06	18:10:17	18:14:37	RAMMING	NEW	0.3	10	---	--	---	LANCASTER SOUND
81-09-19.06	81-11-06	18:31:58	18:39:55	RAMMING	NEW	0.2	9	1.9	1	---	LANCASTER SOUND
81-09-19.07	81-11-06	18:49:52	19:05:49	RAMMING	NEW	0.3	10	---	--	---	LANCASTER SOUND
81-09-19.08	81-11-06	19:10:19	19:30:25	RAMMING	NEW	0.3	10	---	--	---	LANCASTER SOUND
81-09-20.01	81-11-06	19:33:01	19:50:22	RAMMING	NEW	0.2	9	1.9	1	---	LANCASTER SOUND
81-09-20.02	81-11-06	19:51:52	20:45:49	RAMMING	NEW	0.2	9	1.9	1	---	LANCASTER SOUND
81-09-20.03	81-11-06	20:47:32	20:51:29	RAMMING	NEW	0.2	9	1.9	1	---	LANCASTER SOUND
81-09-21.01	81-11-06	00:23:33	00:43:57	CONTINUOUS	NEW	0.2	2	1.9	T	---	LANCASTER SOUND
81-09-21.02	81-11-06	00:44:52	00:49:06	CONTINUOUS	NEW	0.2	2	1.9	T	---	LANCASTER SOUND
81-09-21.03	81-11-06	00:49:34	01:02:42	CONTINUOUS	NEW	0.2	2	1.9	T	---	LANCASTER SOUND
81-09-22.01	81-11-07	14:42:14	15:08:30	RAMMING	NEW	0.2	4	4.9	T	---	LANCASTER SOUND
81-09-22.02	81-11-07	15:16:52	15:23:49	RAMMING	NEW	0.2	4	4.9	T	---	LANCASTER SOUND
81-09-22.03	81-11-07	15:25:17	15:34:46	RAMMING	NEW	0.2	4	4.9	T	---	LANCASTER SOUND
81-09-22.04	81-11-07	15:36:52	16:10:14	RAMMING	NEW	0.2	4	4.9	T	---	LANCASTER SOUND
81-09-22.05	81-11-07	16:11:52	16:35:44	RAMMING	NEW	0.2	4	4.9	T	---	LANCASTER SOUND
81-09-23.01	81-11-07	16:38:53	16:55:40	RAMMING	NEW	0.2	4	4.9	T	---	LANCASTER SOUND
81-09-24.01	81-11-07	17:04:41	17:12:09	RAMMING	NEW	0.2	10	6.1	T	---	LANCASTER SOUND
81-09-24.02	81-11-07	17:19:52	18:03:55	RAMMING	NEW	0.2	10	6.1	T	---	LANCASTER SOUND
81-09-24.03	81-11-07	18:06:21	19:08:30	RAMMING	NEW	0.2	10	6.1	T	---	LANCASTER SOUND
81-09-25.01	81-11-07	20:08:52	20:16:49	RAMMING	NEW	0.3	10	6.1	T	---	ADMIRALTY INLET
81-09-25.02	81-11-07	20:18:12	20:23:09	RAMMING	NEW	0.3	10	6.1	T	---	ADMIRALTY INLET
81-09-25.03	81-11-07	20:24:56	20:24:57	CONTINUOUS	NEW	0.3	10	6.1	T	---	ADMIRALTY INLET
81-09-25.04	81-11-07	20:26:37	20:39:26	CONTINUOUS	NEW	0.3	10	4.0	T	---	ADMIRALTY INLET
81-09-25.05	81-11-07	20:55:33	21:17:30	CONTINUOUS	NEW	0.3	10	4.0	T	---	ADMIRALTY INLET
81-09-25.06	81-11-07	21:21:22	21:35:20	CONTINUOUS	NEW	0.3	10	4.0	T	---	ADMIRALTY INLET
81-09-25.07	81-11-07	22:15:17	22:23:15	CONTINUOUS	NEW	0.3	10	4.0	T	---	ADMIRALTY INLET
81-09-26.01	81-11-07	14:10:55	16:01:02	RAMMING	NEW	0.2	6	4.0	2	---	ADMIRALTY INLET
81-09-26.02	81-11-08	16:29:20	17:39:54	RAMMING	NEW	0.2	10	4.0	T	---	ADMIRALTY INLET
81-09-27.01	81-11-08	18:53:20	18:53:49	CONTINUOUS	NEW	0.3	8	4.0	2	---	ADMIRALTY INLET
81-09-27.02	81-11-08	18:55:12	19:13:38	CONTINUOUS	NEW	0.3	8	4.0	2	---	ADMIRALTY INLET
81-09-28.01	81-11-08	20:20:32	21:10:01	CONTINUOUS	NEW	0.3	4	4.0	4	---	ADMIRALTY INLET
81-09-28.02	81-11-08	21:10:01	21:23:40	RAMMING	NEW	0.3	4	4.0	4	---	ADMIRALTY INLET
81-09-29.01	81-11-08	21:34:12	21:37:13	CONTINUOUS	NEW	0.3	6	4.0	4	---	ADMIRALTY INLET
81-09-29.02	81-11-08	21:37:52	22:03:47	CONTINUOUS	NEW	0.6	10	---	--	---	ADMIRALTY INLET
81-09-30.01	81-11-09	01:32:23	03:39:52	TURNING	NEW	0.6	10	---	--	---	NANISIVIK DOCK
81-10-31.01	81-11-11	20:52:32	23:26:31	CONTINUOUS	NEW	0.6	9	---	--	---	STRATHCONA SOUND
81-10-32.01	81-11-11	23:41:32	02:10:01	CONTINUOUS	NEW	0.6	9	1.8	T	---	LANCASTER SOUND
81-10-33.01	81-11-11	02:58:57	05:27:26	CONTINUOUS	BROKEN	0.6	7	1.8	3	---	LANCASTER SOUND
81-10-34.01	81-11-12	05:56:52	08:33:58	CONTINUOUS	BROKEN	0.6	7	1.8	3	---	LANCASTER SOUND
81-10-35.01	81-11-12	08:35:52	11:15:16	CONTINUOUS	BROKEN	0.6	7	1.8	3	---	LANCASTER SOUND
81-10-36.01	81-11-12	12:05:12	13:46:28	RAMMING	NEW	0.6	7	1.8	3	---	LANCASTER SOUND
81-10-36.02	81-11-12	13:47:17	14:11:48	RAMMING	NEW	0.6	7	1.8	3	---	LANCASTER SOUND

TABLE A2.1 (CONT): M.V. ARCTIC TAPE RECORDS COLLECTED DURING THE PERIOD OF JULY - NOVEMBER 1981

TAPE/FILE	DATE	TIME from	TIME to	TRANSIT MODE	CHANNEL CONDITION	1-yr ICE m	1-yr ICE tenth	OLD ICE m	OLD ICE tenth	RIDGE DEPTH m	LOCATION
81-10-37.01	81-11-12	14:21:12	15:10:49	RAMMING	NEW	0.6	7	1.8	3	---	LANCASTER SOUND
81-10-38.01	81-11-12	15:47:12	15:50:15	RAMMING	NEW	0.6	7	1.8	3	---	LANCASTER SOUND
81-10-38.02	81-11-12	15:50:37	16:49:38	RAMMING	NEW	0.6	7	1.8	3	---	LANCASTER SOUND
81-10-39.01	81-11-12	17:25:52	19:45:37	RAMMING	NEW	0.6	7	1.8	3	---	LANCASTER SOUND
81-10-39.02	81-11-12	19:46:17	19:46:19	RAMMING	NEW	0.6	7	1.8	3	---	LANCASTER SOUND
81-10-39.03	81-11-12	19:47:32	19:56:35	RAMMING	NEW	0.6	7	1.8	3	---	LANCASTER SOUND
81-10-40.01	81-11-12	20:00:32	21:14:30	RAMMING	NEW	0.6	7	1.8	3	---	LANCASTER SOUND
81-10-41.01	81-11-12	21:20:19	23:12:11	RAMMING	NEW	0.6	7	1.8	3	---	LANCASTER SOUND
81-10-42.A1	81-11-12	23:18:32	01:02:00	RAMMING	NEW	0.6	7	1.8	3	---	LANCASTER SOUND
81-10-42.B1	81-11-13	01:24:38	03:59:07	RAMMING	NEW	0.6	7	1.8	3	---	NAVY BOARD INLET
81-10-43.01	81-11-13	13:32:21	14:35:17	RAMMING	NEW	0.6	7	1.8	3	---	NAVY BOARD INLET
81-10-43.02	81-11-13	14:36:12	15:23:07	RAMMING	NEW	0.6	7	1.8	3	---	NAVY BOARD INLET
81-10-43.03	81-11-13	15:45:12	16:37:47	RAMMING	NEW	0.6	7	1.8	3	---	NAVY BOARD INLET
81-10-44.01	81-11-13	16:24:32	16:28:49	RAMMING	NEW	0.6	7	1.8	3	---	NAVY BOARD INLET
81-10-44.02	81-11-14	17:42:40	18:27:38	RAMMING	NEW	0.6	7	1.8	3	S	NAVY BOARD INLET
81-10-44.03	81-11-14	18:02:55	18:06:11	RAMMING	NEW	0.6	9	1.2	1	---	POND INLET
81-10-44.04	81-11-14	20:33:52	22:16:47	RAMMING	NEW	0.6	9	1.2	1	---	POND INLET
81-10-44.05	81-11-14	22:17:17	22:17:18	RAMMING	NEW	0.6	9	1.2	1	---	POND INLET
81-10-44.06	81-11-14	22:18:04	22:27:36	RAMMING	NEW	0.6	9	1.2	1	---	POND INLET
81-10-45.01	81-11-14	22:27:48	22:56:29	RAMMING	NEW	0.6	7	1.8	3	---	POND INLET
81-10-46.01	81-11-15	10:13:38	13:21:42	RAMMING	NEW	0.6	7	1.8	3	S	POND INLET
81-10-47.01	81-11-15	15:18:31	16:07:11	RAMMING	NEW	0.6	7	1.8	3	S	POND INLET
81-10-47.02	81-11-15	16:07:54	16:30:51	RAMMING	NEW	0.6	7	1.8	3	S	POND INLET
81-10-47.03	81-11-15	16:41:12	16:51:02	RAMMING	NEW	0.6	7	1.8	3	S	POND INLET
81-10-47.04	81-11-15	16:56:32	16:54:10	RAMMING	NEW	0.6	7	1.8	3	S	POND INLET
81-10-47.05	81-11-15	17:01:18	18:08:43	RAMMING	NEW	0.6	7	1.8	3	S	POND INLET
81-10-48.01	81-11-15	20:03:55	20:55:55	RAMMING	NEW	0.6	7	1.8	3	S	POND INLET
81-10-49.01	81-11-15	22:38:38	23:16:19	RAMMING	NEW	0.3	9	1.8	1	---	BAFFIN BAY
81-10-49.02	81-11-15	23:17:38	23:26:08	RAMMING	NEW	0.2	9	1.8	1	---	BAFFIN BAY

APPENDIX 3

LIST OF IDENTIFIED ICE/PROPELLER INTERACTION EVENTS

(Table A3.1 - Identified Ice/Propeller Interaction Events)

A3.1 : IDENTIFIED ICE/PROPELLER INTERACTION EVENTS

No.	SHAFT TORQUE kN @ < MAX	SHAFT TORQUE kN @ < MEAN	SHAFT THRUST kN @ < MAX	SHAFT THRUST kN @ < MEAN	MEAN SHAFT POWER kW	MEAN SPEED knots	TRANSIT MODE	CHANNEL CONDITION	1-YR ICE @	1-YR ICE tenth	OLD ICE @	OLD ICE tenth	ICE RIDGE DEPTH @	DATE Yr-Mon-Day	TIME Hr : Min	LOCATION
1	201	94	96	67	1040	5.6	CONTINUOUS	NEW	1.5	1	---	--	---	81- 7- 5	17 : 35	Lancaster Sound
2	185	126	149	119	1469	6.0	CONTINUOUS	NEW	1.5	1	---	--	---	81- 7- 5	17 : 42	Lancaster Sound
3	277	209	287	204	2889	9.7	CONTINUOUS	NEW	1.5	1	---	--	---	81- 7- 5	19 : 21	Lancaster Sound
4	114	63	-140	-57	657	9.5	RAMMING	NEW	1.5	1	---	--	---	81- 7- 5	19 : 59	Lancaster Sound
5	141	63	-147	-50	661	9.1	RAMMING	NEW	1.5	1	---	--	---	81- 7- 5	20 : 0	Lancaster Sound
6	118	72	32	13	744	5.7	CONTINUOUS	NEW	1.5	1	---	--	---	81- 7- 5	20 : 4	Lancaster Sound
7	103	76	48	31	788	4.9	CONTINUOUS	NEW	1.5	1	---	--	---	81- 7- 5	20 : 7	Lancaster Sound
8	147	76	55	30	785	4.7	CONTINUOUS	NEW	1.5	1	---	--	---	81- 7- 5	20 : 8	Lancaster Sound
9	195	134	158	130	1642	5.1	CONTINUOUS	NEW	1.5	1	---	--	---	81- 7- 5	20 : 11	Lancaster Sound
10	197	144	195	105	1910	9.5	CONTINUOUS	NEW	1.5	1	---	--	---	81- 7- 5	20 : 42	Lancaster Sound
11	302	205	-391	-316	2632	.6	RAMMING	NEW	1.5	10	---	--	2.3	81- 7- 7	2 : 19	Admiralty Inlet
12	134	61	149	61	571	.8	RAMMING	NEW	1.5	10	---	--	2.3	81- 7- 7	2 : 21	Admiralty Inlet
13	188	82	-154	-104	873	1.0	RAMMING	NEW	1.5	10	---	--	2.3	81- 7- 7	2 : 25	Admiralty Inlet
14	235	128	-237	-173	1599	.7	RAMMING	NEW	1.5	10	---	--	2.3	81- 7- 7	2 : 37	Admiralty Inlet
15	365	264	-508	-407	3403	.5	RAMMING	NEW	1.5	10	---	--	2.3	81- 7- 7	2 : 43	Admiralty Inlet
16	305	178	-393	-256	2155	1.0	RAMMING	NEW	1.5	10	---	--	2.3	81- 7- 7	2 : 54	Admiralty Inlet
17	331	224	-437	-349	2836	.4	RAMMING	NEW	1.5	10	---	--	2.3	81- 7- 7	2 : 59	Admiralty Inlet
18	325	138	367	161	1394	1.1	RAMMING	NEW	1.5	10	---	--	2.3	81- 7- 7	3 : 3	Admiralty Inlet
19	417	243	496	300	3045	.3	RAMMING	NEW	1.5	10	---	--	2.3	81- 7- 7	3 : 3	Admiralty Inlet
20	509	388	-763	-597	5474	2.7	RAMMING	NEW	1.5	10	---	--	2.3	81- 7- 7	4 : 10	Admiralty Inlet
21	379	254	464	319	3148	1.9	RAMMING	NEW	1.5	10	---	--	2.3	81- 7- 7	4 : 12	Admiralty Inlet
22	147	85	184	95	881	2.3	RAMMING	NEW	1.5	10	---	--	2.3	81- 7- 7	4 : 18	Admiralty Inlet
23	417	196	508	236	2204	2.0	RAMMING	NEW	1.5	10	---	--	2.3	81- 7- 7	4 : 41	Admiralty Inlet
24	161	95	-161	-113	1054	1.1	RAMMING	NEW	1.5	10	---	--	2.3	81- 7- 7	4 : 42	Admiralty Inlet
25	248	112	278	135	1130	.8	RAMMING	NEW	1.5	10	---	--	2.3	81- 7- 7	4 : 46	Admiralty Inlet
26	448	221	-740	-321	2649	.1	RAMMING	NEW	1.5	10	---	--	2.3	81- 7- 7	5 : 8	Admiralty Inlet
27	479	333	-809	-500	4513	.4	RAMMING	NEW	1.5	10	---	--	2.3	81- 7- 7	5 : 8	Admiralty Inlet
28	459	290	-598	-446	3949	.7	RAMMING	NEW	1.5	10	---	--	2.3	81- 7- 7	5 : 9	Admiralty Inlet
29	394	285	-536	-433	3886	1.0	RAMMING	NEW	1.5	10	---	--	2.3	81- 7- 7	5 : 10	Admiralty Inlet
30	533	303	625	353	3648	2.8	RAMMING	NEW	1.6	10	---	--	4.9	81- 7- 7	14 : 3	Admiralty Inlet

A3.1 (CONT) : IDENTIFIED ICE/PROPELLER INTERACTION EVENTS

No.	SHAFT TORQUE kN m < MAX	SHAFT TORQUE kN m >< MEAN	SHAFT THRUST kN >< MAX	SHAFT THRUST kN >< MEAN >	MEAN SHAFT POWER kW	MEAN SPEED knots	TRANSIT MODE	CHANNEL CONDITION	1-YR ICE m	1-YR ICE tenth	OLD ICE m	OLD ICE tenth	ICE RIDGE DEPTH m	DATE Yr-Mon-Day	TIME Hr : Min	LOCATION
31	632	401	783	481	5132	1.0	RAMMING	NEW	1.6	10	---	--	4.9	81- 7- 7	14 : 4	Admiralty Inlet
32	305	156	344	182	1733	2.1	RAMMING	NEW	1.6	10	---	--	4.9	81- 7- 7	14 : 14	Admiralty Inlet
33	356	252	-451	-354	3156	1.2	RAMMING	NEW	1.6	10	---	--	4.9	81- 7- 7	14 : 21	Admiralty Inlet
34	336	249	-439	-347	3109	1.8	RAMMING	NEW	1.6	10	---	--	4.9	81- 7- 7	14 : 22	Admiralty Inlet
35	343	255	-448	-357	3207	1.3	RAMMING	NEW	1.6	10	---	--	4.9	81- 7- 7	14 : 58	Admiralty Inlet
36	926	473	1174	586	6439	3.0	RAMMING	NEW	1.6	10	---	--	---	81- 7- 8	14 : 18	Admiralty Inlet
37	1077	668	1174	848	9933	.3	RAMMING	NEW	1.6	10	---	--	---	81- 7- 8	14 : 35	Admiralty Inlet
38	819	606	1048	772	3732	4.5	RAMMING	NEW	1.6	10	---	--	---	81- 7- 8	14 : 42	Admiralty Inlet
39	814	471	1174	590	6560	2.0	RAMMING	NEW	1.6	10	---	--	---	81- 7- 8	14 : 51	Admiralty Inlet
40	392	290	377	352	3782	.2	RAMMING	NEW	1.5	10	---	--	---	81- 7- 8	23 : 15	Admiralty Inlet
41	707	401	629	494	5795	8.8	CONTINUOUS	BROKEN	1.5	10	---	--	---	81- 7-12	6 : 22	Admiralty Inlet
42	414	289	425	317	4025	11.5	CONTINUOUS	BROKEN	1.5	10	---	--	---	81- 7-12	7 : 14	Admiralty Inlet
43	410	307	774	347	4276	11.0	CONTINUOUS	BROKEN	1.5	10	---	--	---	81- 7-12	7 : 50	Admiralty Inlet
44	453	316	469	367	4401	11.0	CONTINUOUS	BROKEN	1.5	10	---	--	---	81- 7-12	7 : 52	Admiralty Inlet
45	244	183	236	182	2403	8.3	CONTINUOUS	NEW	0.5	8	---	--	---	81-11- 3	17 : 0	Baffin Bay
46	257	190	273	202	2503	6.7	CONTINUOUS	NEW	0.5	8	---	--	---	81-11- 3	17 : 17	Baffin Bay
47	311	236	324	258	3188	8.4	CONTINUOUS	NEW	0.2	7	---	--	---	81-11- 3	18 : 45	Baffin Bay
48	287	186	241	201	2368	6.9	CONTINUOUS	NEW	0.2	10	---	--	---	81-11- 3	21 : 28	Baffin Bay
49	257	191	255	212	2432	6.3	CONTINUOUS	NEW	0.2	10	---	--	---	81-11- 3	21 : 32	Baffin Bay
50	219	128	142	122	1454	3.0	CONTINUOUS	NEW	0.3	1	---	--	---	81-11- 4	20 : 43	Bylot Island
51	204	155	179	160	1842	2.9	CONTINUOUS	NEW	0.3	6	1.2	3	---	81-11- 4	21 : 16	Bylot Island
52	278	157	-251	-169	1899	.8	RAMMING	NEW	0.3	6	1.2	3	---	81-11- 4	21 : 29	Bylot Island
53	309	210	276	242	2702	2.8	CONTINUOUS	NEW	0.3	6	1.2	3	---	81-11- 4	22 : 7	Bylot Island
54	185	89	-55	-31	950	1.8	RAMMING	NEW	0.3	6	1.2	3	---	81-11- 4	22 : 37	Bylot Island
55	186	75	25	12	694	.2	CONTINUOUS	NEW	0.3	6	1.2	3	---	81-11- 5	13 : 23	Bylot Island
56	451	338	-715	-484	4379	3.7	RAMMING	NEW	0.3	10	---	--	---	81-11- 5	19 : 40	Lancaster Sound
57	307	201	-343	-236	2334	.3	RAMMING	NEW	0.3	10	---	--	---	81-11- 5	20 : 10	Lancaster Sound
58	448	344	-646	-476	4678	1.3	RAMMING	NEW	0.3	10	---	--	---	81-11- 5	20 : 22	Lancaster Sound
59	405	256	503	324	3380	3.9	CONTINUOUS	NEW	0.2	2	1.9	1	---	81-11- 6	0 : 56	Lancaster Sound
60	192	65	60	37	650	3.1	RAMMING	NEW	0.2	9	1.9	1	---	81-11- 6	20 : 24	Lancaster Sound

A3.1 (CONT) : IDENTIFIED ICE/PROPELLER INTERACTION EVENTS

No.	SHAFT TORQUE kN ▪ < MAX	>< MEAN	SHAFT THRUST kN >< MAX	>< MEAN >	MEAN SHAFT POWER kW	MEAN SPEED knots	TRANSIT MODE	CHANNEL CONDITION	1-YR ICE ▪	tenth	OLD ICE ▪	tenth	ICE RIDGE DEPTH ▪	DATE Yr-Mon-Day	TIME Hr : Min	LOCATION
61	388	282	393	357	3806	3.1	RAMMING	NEW	0.2	9	1.9	1	---	81-11- 6	20 : 40	Lancaster Sound
62	235	160	-264	-195	1972	.2	RAMMING	NEW	0.2	4	4.9	T	---	81-11- 7	16 : 31	Lancaster Sound
63	341	253	441	317	3160	.8	RAMMING	NEW	0.2	4	4.9	T	---	81-11- 7	16 : 45	Lancaster Sound
64	374	154	459	183	1725	.7	RAMMING	NEW	0.2	10	6.1	T	---	81-11- 7	17 : 41	Lancaster Sound
65	466	243	590	306	2881	.9	RAMMING	NEW	0.2	10	6.1	T	---	81-11- 7	17 : 41	Lancaster Sound
66	322	166	416	198	1800	1.8	RAMMING	NEW	0.2	10	6.1	T	---	81-11- 7	17 : 42	Lancaster Sound
67	753	327	462	404	4453	6.7	CONTINUOUS	NEW	0.3	10	4.0	T	---	81-11- 7	20 : 32	Admiralty Inlet
68	745	499	898	614	7385	7.1	CONTINUOUS	NEW	0.3	10	4.0	T	---	81-11- 7	20 : 37	Admiralty Inlet
69	313	169	239	193	2070	3.7	CONTINUOUS	NEW	0.3	10	4.0	T	---	81-11- 7	21 : 6	Admiralty Inlet
70	208	135	163	147	1584	3.7	CONTINUOUS	NEW	0.3	10	4.0	T	---	81-11- 7	21 : 7	Admiralty Inlet
71	213	136	172	148	1585	3.5	CONTINUOUS	NEW	0.3	10	4.0	T	---	81-11- 7	21 : 9	Admiralty Inlet
72	286	169	220	193	2133	4.4	CONTINUOUS	NEW	0.3	10	4.0	T	---	81-11- 7	21 : 34	Admiralty Inlet
73	567	323	632	355	4407	2.1	RAMMING	NEW	0.2	6	4.0	2	---	81-11- 8	14 : 34	Admiralty Inlet
74	772	453	1151	583	6383	2.8	RAMMING	NEW	0.2	6	4.0	2	---	81-11- 8	14 : 48	Admiralty Inlet
75	340	251	390	296	3177	1.8	RAMMING	NEW	0.2	6	4.0	2	---	81-11- 8	15 : 50	Admiralty Inlet
76	257	188	250	210	2347	4.9	CONTINUOUS	NEW	0.3	4	4.0	4	---	81-11- 8	20 : 36	Admiralty Inlet
77	406	289	402	346	3870	6.1	CONTINUOUS	NEW	0.3	4	4.0	4	---	81-11- 8	20 : 51	Admiralty Inlet
78	277	165	202	174	2090	4.0	CONTINUOUS	BROKEN	0.6	7	1.8	3	---	81-11-11	4 : 0	Lancaster Sound
79	780	408	1174	501	5541	1.5	CONTINUOUS	BROKEN	0.6	7	1.8	3	---	81-11-11	5 : 12	Lancaster Sound
80	882	515	1174	660	7574	4.5	CONTINUOUS	BROKEN	0.6	7	1.8	3	---	81-11-11	5 : 14	Lancaster Sound
81	781	473	1068	642	7015	4.9	CONTINUOUS	BROKEN	0.6	7	1.8	3	---	81-11-11	5 : 15	Lancaster Sound
82	253	184	241	216	2292	4.5	CONTINUOUS	NEW	0.6	9	1.8	T	---	81-11-12	2 : 9	Lancaster Sound
83	253	121	172	123	1324	3.6	CONTINUOUS	BROKEN	0.6	7	1.8	3	---	81-11-12	7 : 44	Lancaster Sound
84	230	152	209	183	1806	3.5	CONTINUOUS	BROKEN	0.6	7	1.8	3	---	81-11-12	10 : 1	Lancaster Sound
85	695	526	1082	702	7574	1.4	CONTINUOUS	BROKEN	0.6	7	1.8	3	---	81-11-12	10 : 40	Lancaster Sound
86	401	292	452	399	3876	5.2	RAMMING	NEW	0.6	7	1.8	3	---	81-11-12	14 : 48	Lancaster Sound
87	882	631	1174	868	9582	2.9	RAMMING	NEW	0.6	7	1.8	3	---	81-11-12	14 : 56	Lancaster Sound
88	832	432	1087	566	5716	.4	RAMMING	NEW	0.6	7	1.8	3	---	81-11-12	17 : 28	Lancaster Sound
89	156	89	-145	-82	1046	.3	RAMMING	NEW	0.6	7	1.8	3	---	81-11-12	18 : 37	Lancaster Sound
90	837	583	1174	750	8616	6.2	RAMMING	NEW	0.6	7	1.8	3	---	81-11-12	21 : 45	Lancaster Sound

A3.1 (CONT) : IDENTIFIED ICE/PROPELLER INTERACTION EVENTS

No.	SHAFT TORQUE kN @ < MAX	SHAFT TORQUE kN @ < MEAN	SHAFT THRUST kN @ < MAX	SHAFT THRUST kN @ < MEAN	MEAN SHAFT POWER kW	MEAN SPEED knots	TRANSIT MODE	CHANNEL CONDITION	1-YR ICE @	1-YR ICE tenth	OLD ICE @	OLD ICE tenth	ICE RIDGE DEPTH @	DATE Yr-Mon-Day	TIME Hr	TIME Min	LOCATION
91	790	483	1174	622	6757	.2	RAMMING	NEW	0.6	7	1.8	3	---	81-11-12	22	6	Lancaster Sound
92	983	516	1174	681	7801	.5	RAMMING	NEW	0.6	7	1.8	3	---	81-11-13	2	25	Navy Board Inlet
93	992	565	1126	729	8539	1.3	RAMMING	NEW	0.6	7	1.8	3	---	81-11-13	2	31	Navy Board Inlet
94	832	523	1174	715	7207	2.7	RAMMING	NEW	0.6	7	1.8	3	---	81-11-13	2	47	Navy Board Inlet
95	356	244	-435	-335	3151	.1	RAMMING	NEW	0.6	7	1.8	3	---	81-11-13	3	13	Navy Board Inlet
96	579	355	-710	-482	4878	2.9	RAMMING	NEW	0.6	7	1.8	3	---	81-11-13	3	27	Navy Board Inlet
97	469	357	-765	-494	4901	2.8	RAMMING	NEW	0.6	7	1.8	3	---	81-11-13	3	27	Navy Board Inlet
98	482	321	-609	-443	4295	1.6	RAMMING	NEW	0.6	7	1.8	3	---	81-11-13	13	58	Navy Board Inlet
99	441	331	-618	-449	4346	2.7	RAMMING	NEW	0.6	7	1.8	3	---	81-11-13	14	18	Navy Board Inlet
100	322	235	-407	-305	3070	.7	RAMMING	NEW	0.6	9	1.2	1	---	81-11-14	22	6	Pond Inlet
101	634	437	-827	-620	6062	5.2	RAMMING	NEW	0.6	7	1.8	3	S	81-11-15	10	33	Pond Inlet
102	554	420	-816	-558	5839	2.9	RAMMING	NEW	0.6	7	1.8	3	S	81-11-15	10	40	Pond Inlet
103	107	52	34	17	483	.3	RAMMING	NEW	0.6	7	1.8	3	S	81-11-15	12	28	Pond Inlet
104	154	52	37	18	483	.3	RAMMING	NEW	0.6	7	1.8	3	S	81-11-15	12	31	Pond Inlet
105	116	52	32	18	487	.4	RAMMING	NEW	0.6	7	1.8	3	S	81-11-15	12	33	Pond Inlet
106	639	386	825	459	5723	.6	RAMMING	NEW	0.6	7	1.8	3	S	81-11-15	13	12	Pond Inlet
107	516	397	-846	-596	5578	.2	RAMMING	NEW	0.6	7	1.8	3	S	81-11-15	13	13	Pond Inlet
108	365	257	342	286	3437	7.2	RAMMING	NEW	0.6	7	1.8	3	S	81-11-15	16	2	Pond Inlet
109	213	102	89	69	1122	3.9	RAMMING	NEW	0.6	7	1.8	3	S	81-11-15	17	43	Pond Inlet
110	311	172	347	178	2096	4.4	RAMMING	NEW	0.3	9	1.8	1	---	81-11-15	22	49	Baffin Bay
111	639	481	843	603	6896	3.4	RAMMING	NEW	0.3	9	1.8	1	---	81-11-15	22	58	Baffin Bay

APPENDIX 4

DEDUCED M.V. ARCTIC PROPULSIVE PERFORMANCE DATA IN VARIOUS CATEGORIES

(Figures A4.1 through A4.68)

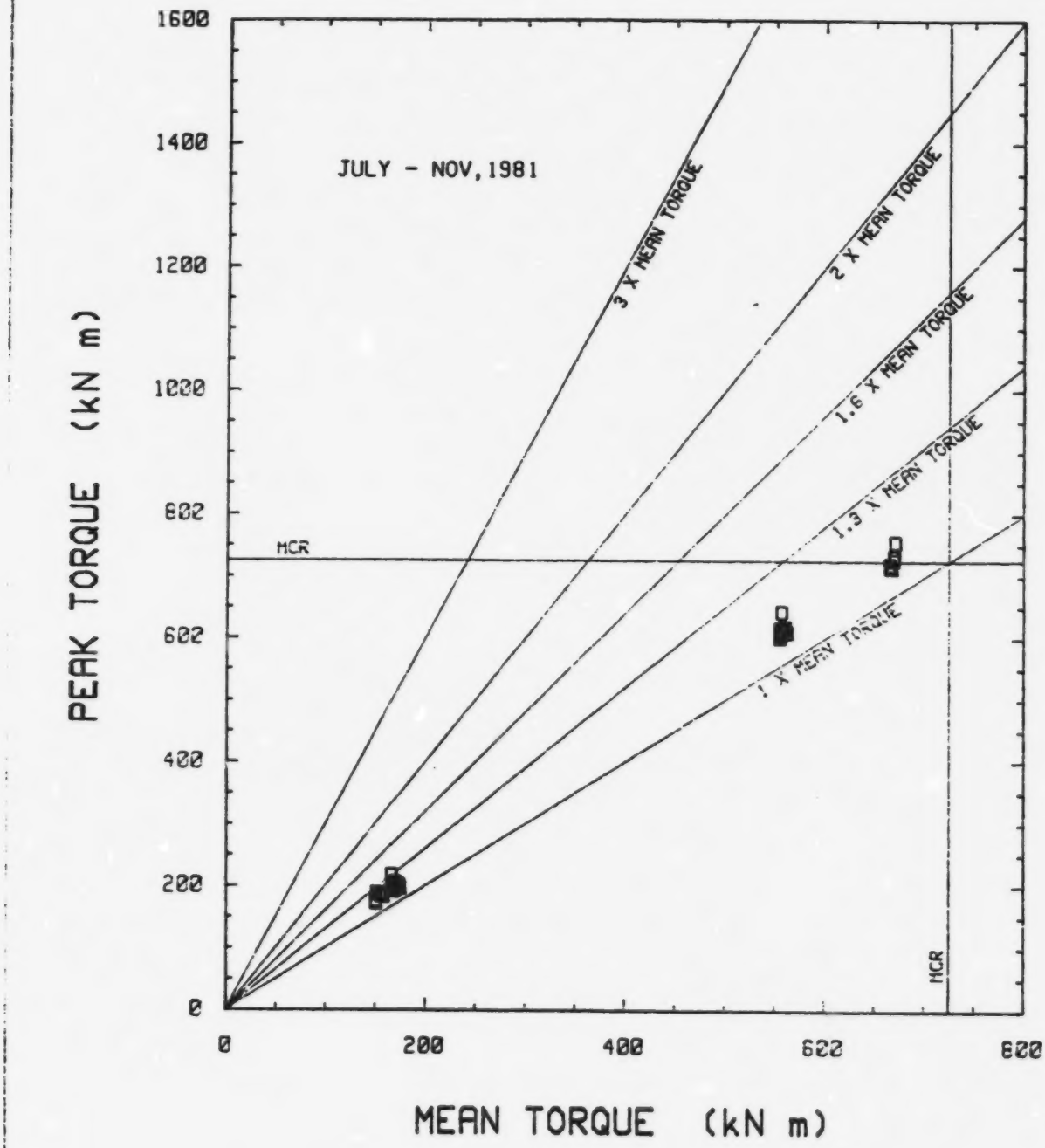

FIG. A4.1 SHAFT TORQUE EXCURSIONS IN OPEN WATER

(Category 1.1 : OPEN WATER, SMOOTH SEASTATE)

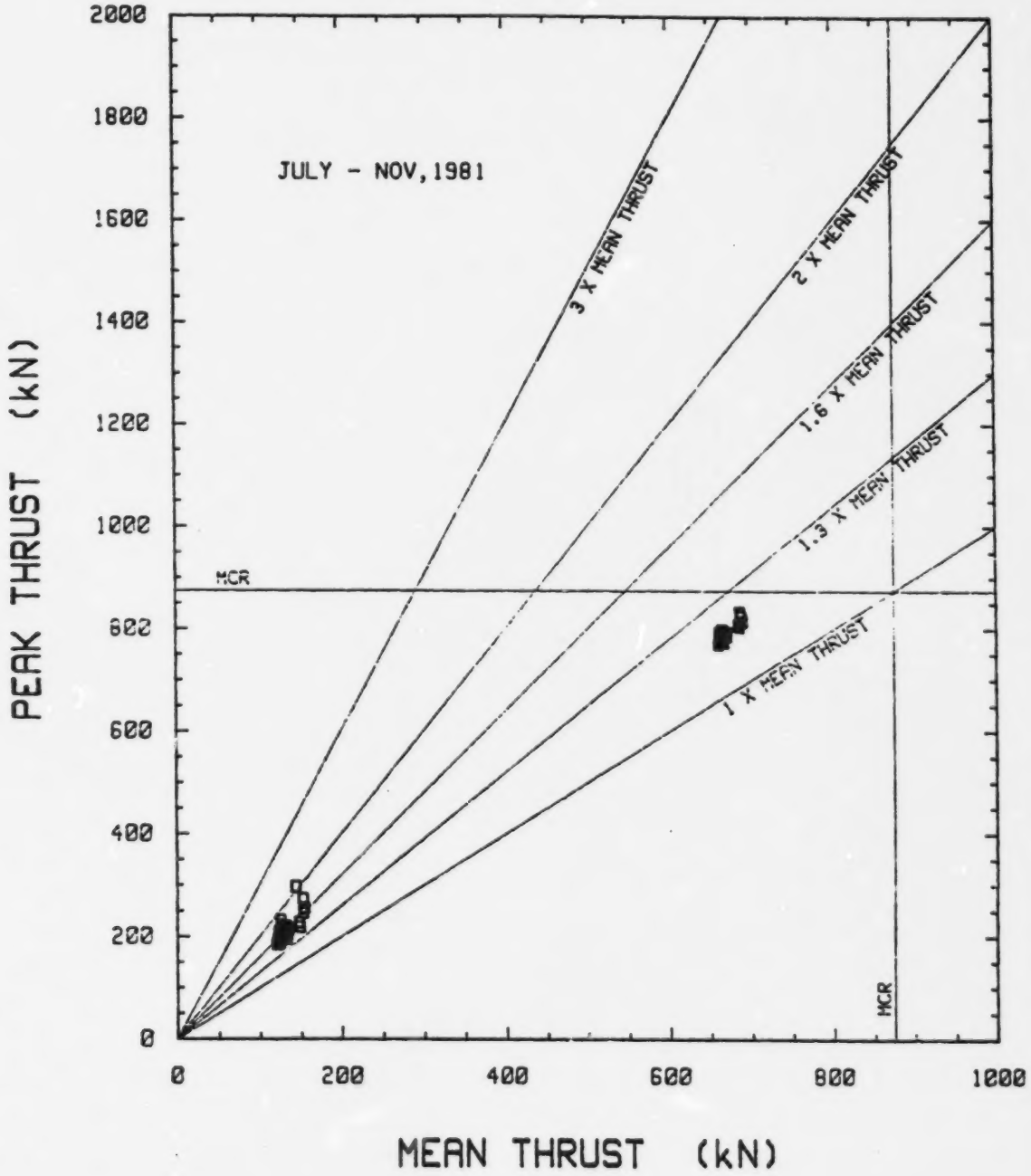

FIG. A4.2 SHAFT THRUST EXCURSIONS IN OPEN WATER

(Category 1.1 : OPEN WATER, SMOOTH SEASTATE)

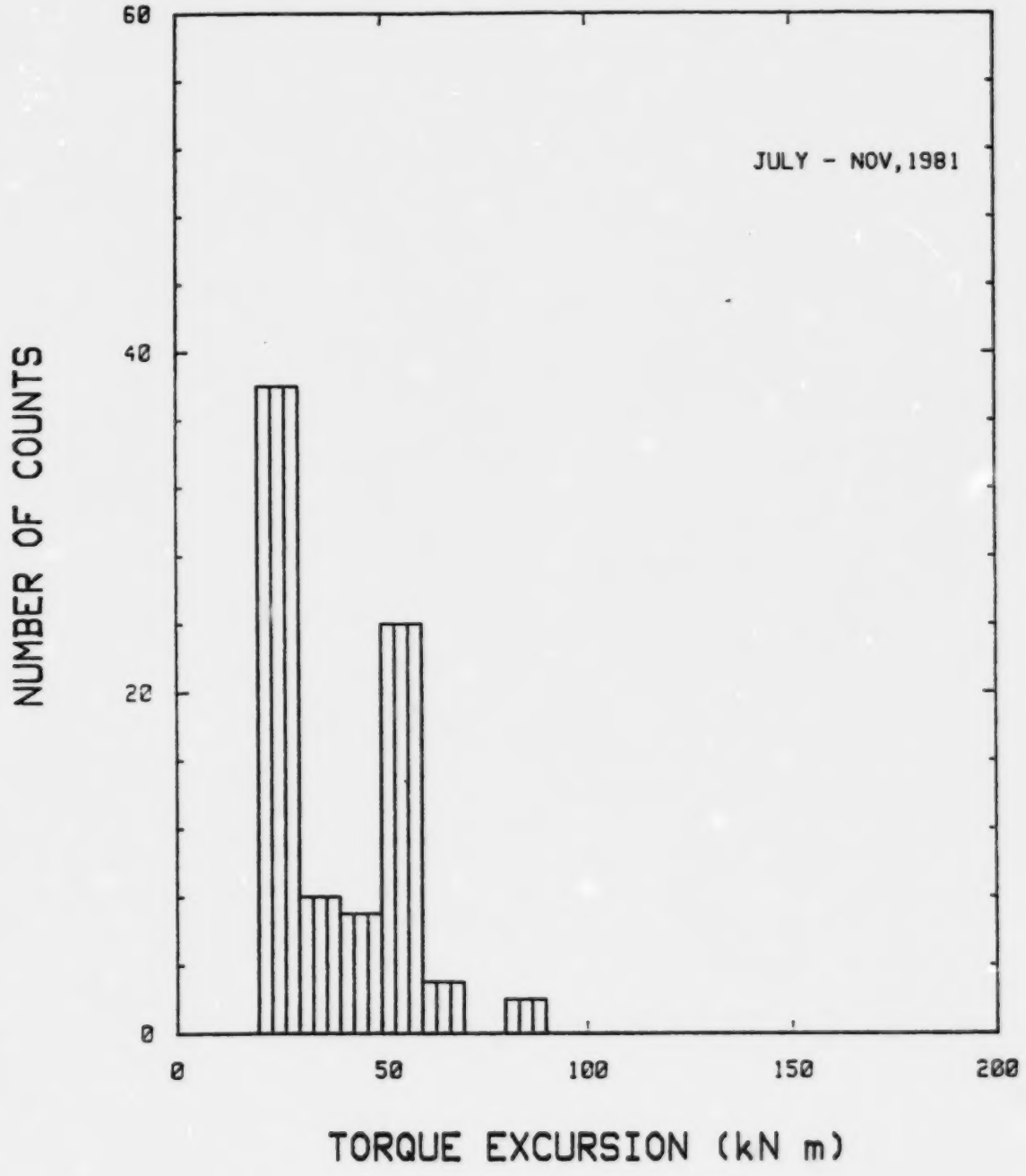

FIG. A4.3 SHAFT TORQUE EXCURSIONS IN OPEN WATER

(Category 1.1 : OPEN WATER, SMOOTH SEASTATE)

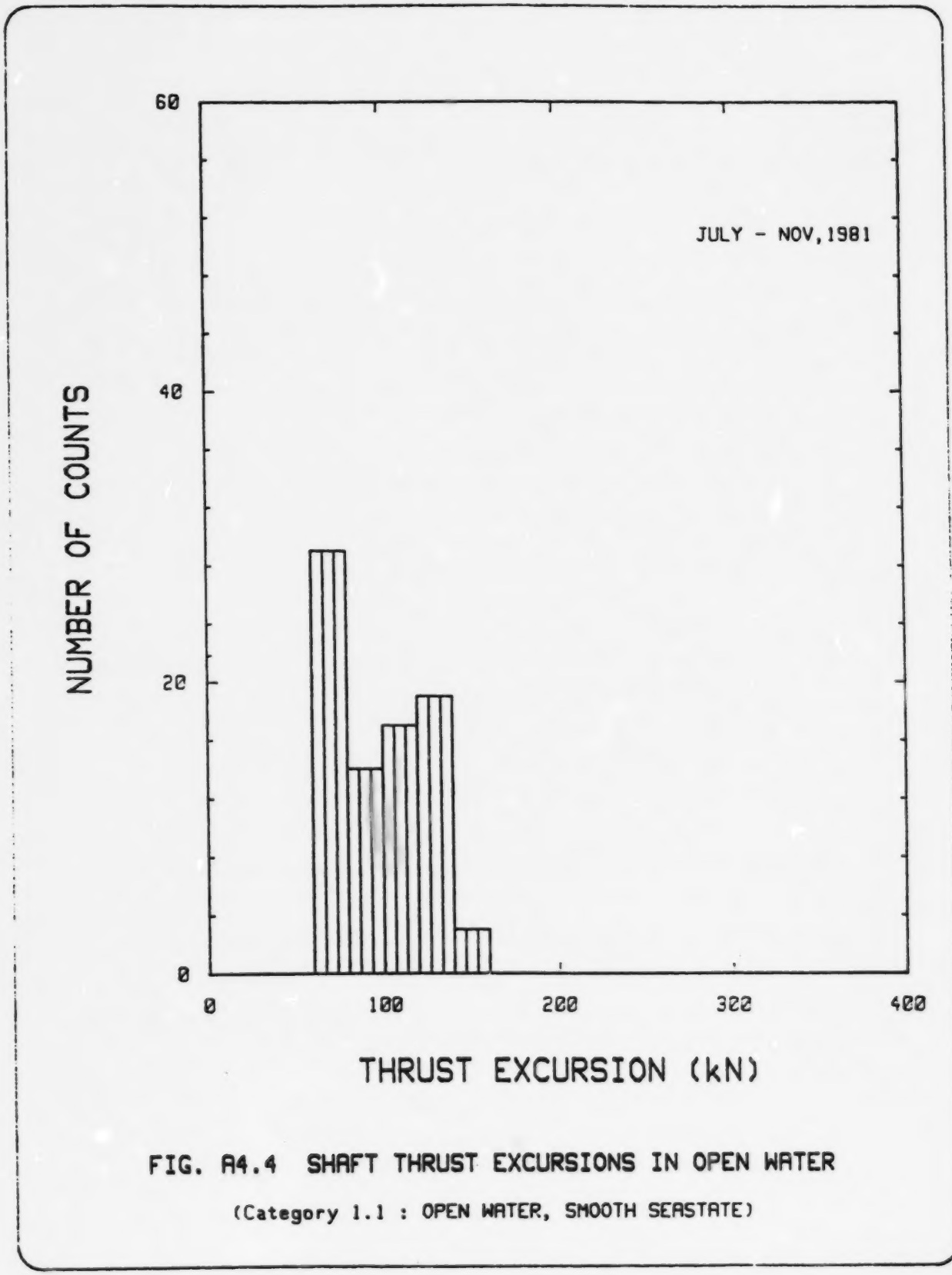

FIG. A4.4 SHAFT THRUST EXCURSIONS IN OPEN WATER

(Category 1.1 : OPEN WATER, SMOOTH SEASTATE)

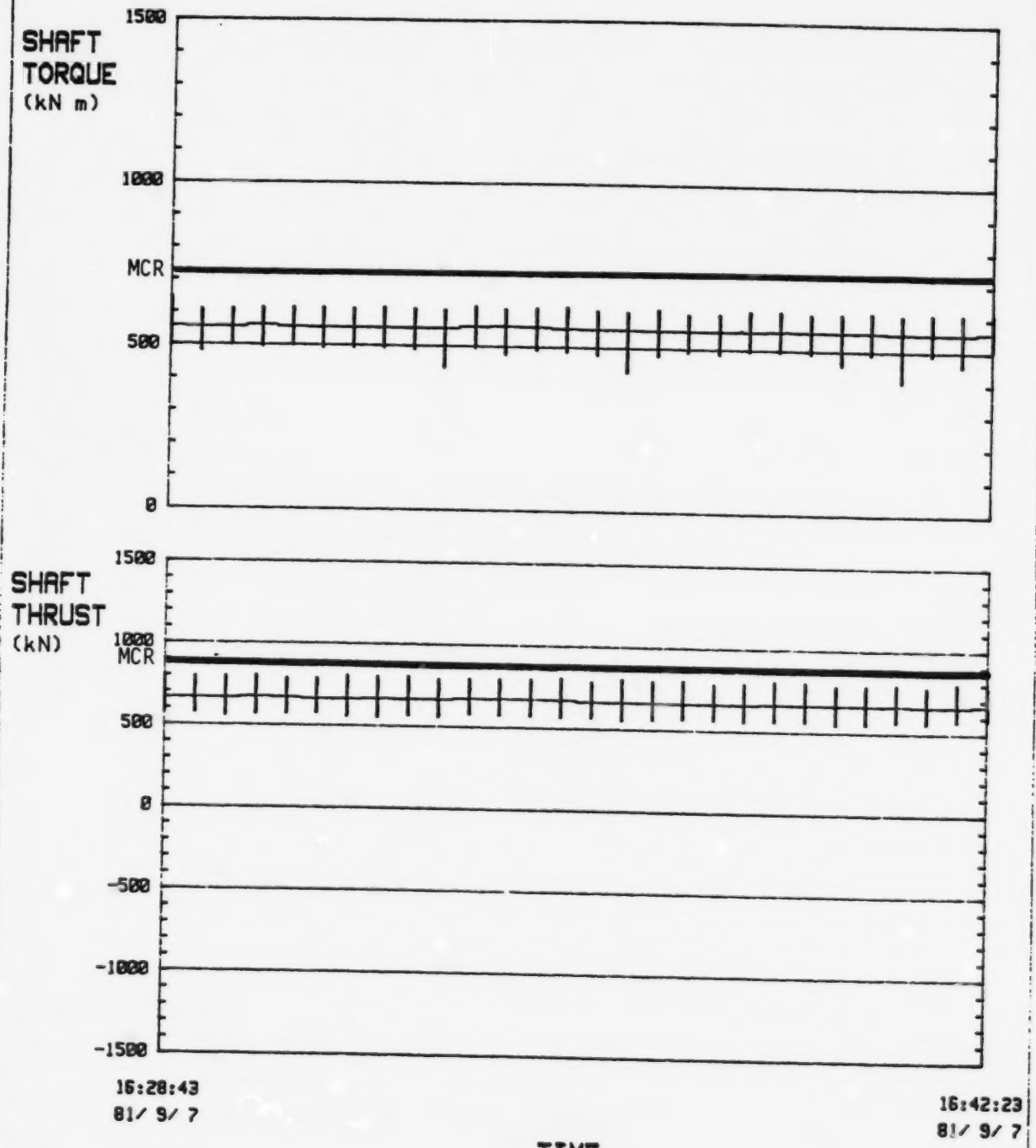

FIG. A4.5 PROPULSIVE PERFORMANCE RECORD

(OPEN WATER, SMOOTH SEASTATE)

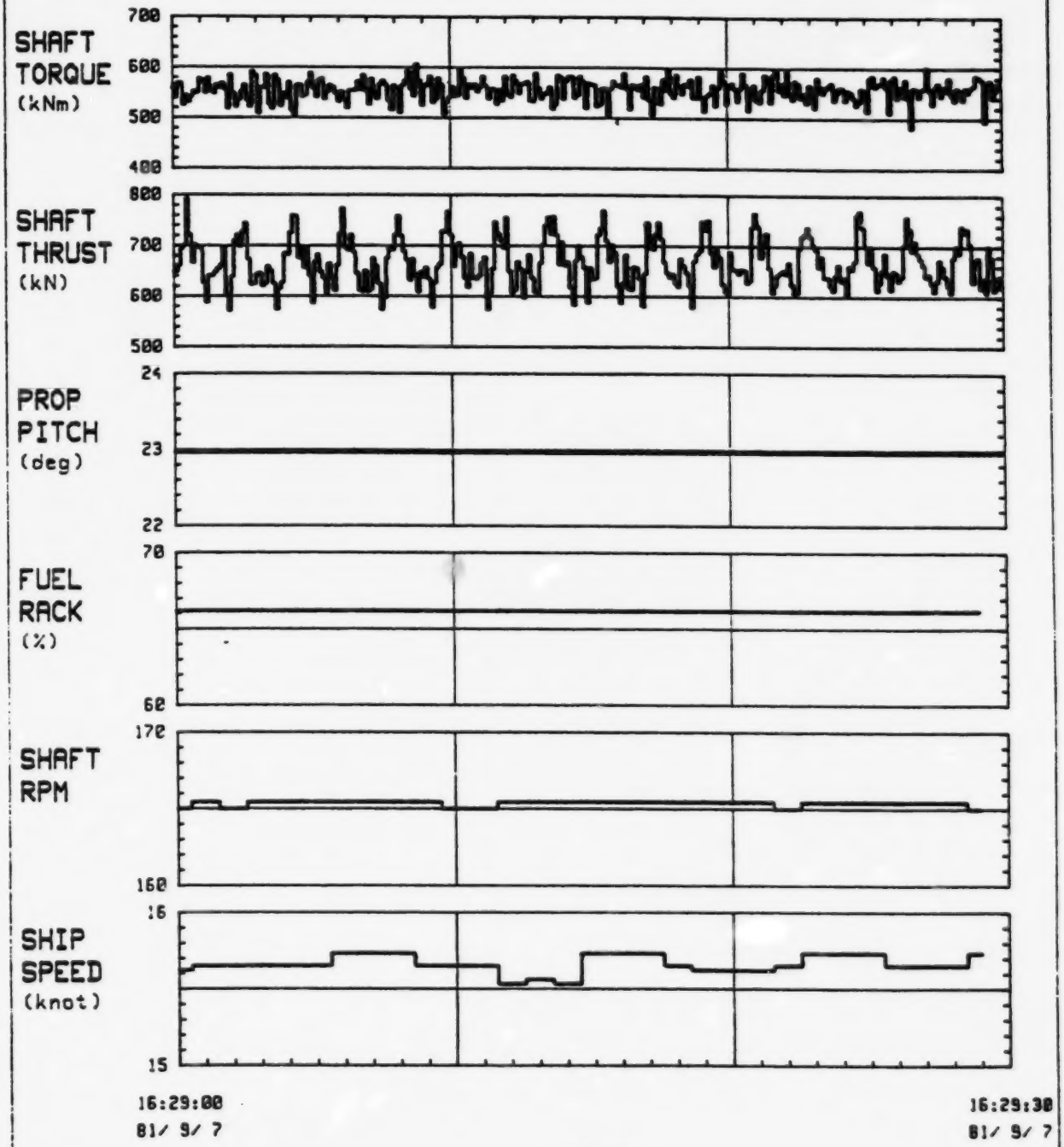

FIG. A4.6 PROPULSIVE PERFORMANCE RECORD

(OPEN WATER, SMOOTH SEASTATE)

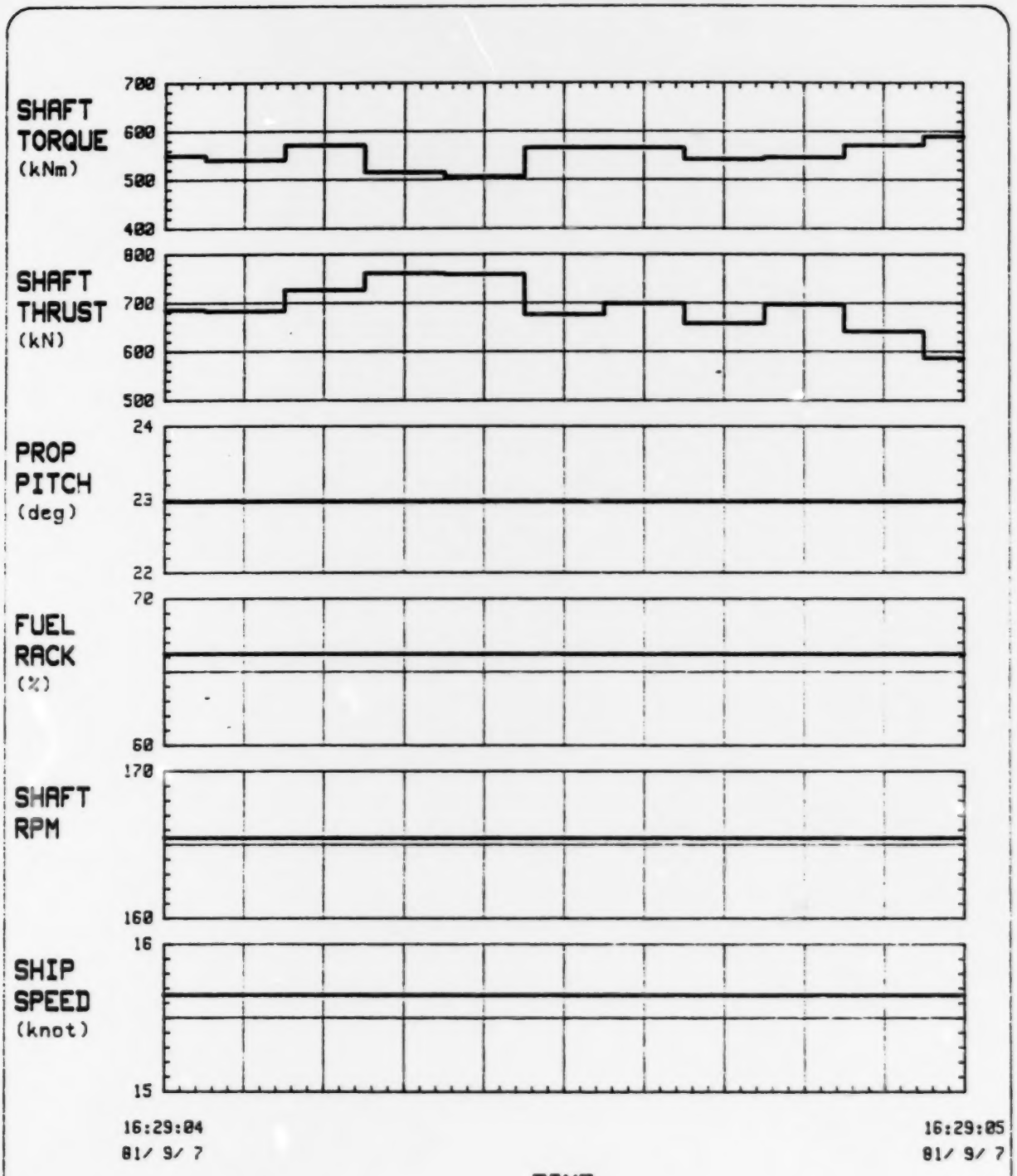

FIG. A4.7 PROPULSIVE PERFORMANCE RECORD

(OPEN WATER, SMOOTH SEASTATE)

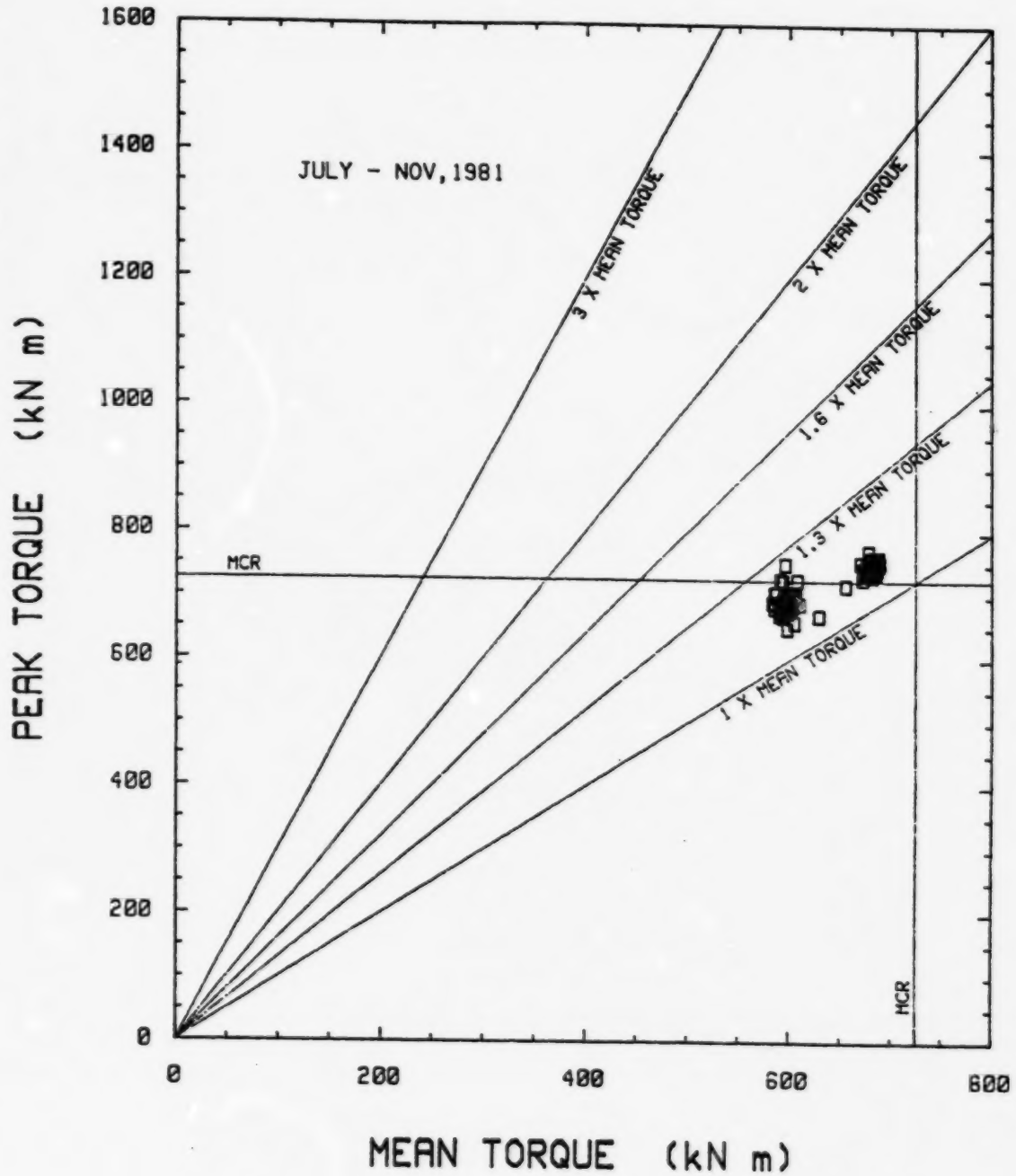

FIG. A4.8 SHAFT TORQUE EXCURSIONS IN OPEN WATER

(Category 1.2 : OPEN WATER, ROUGH SEASTATE)

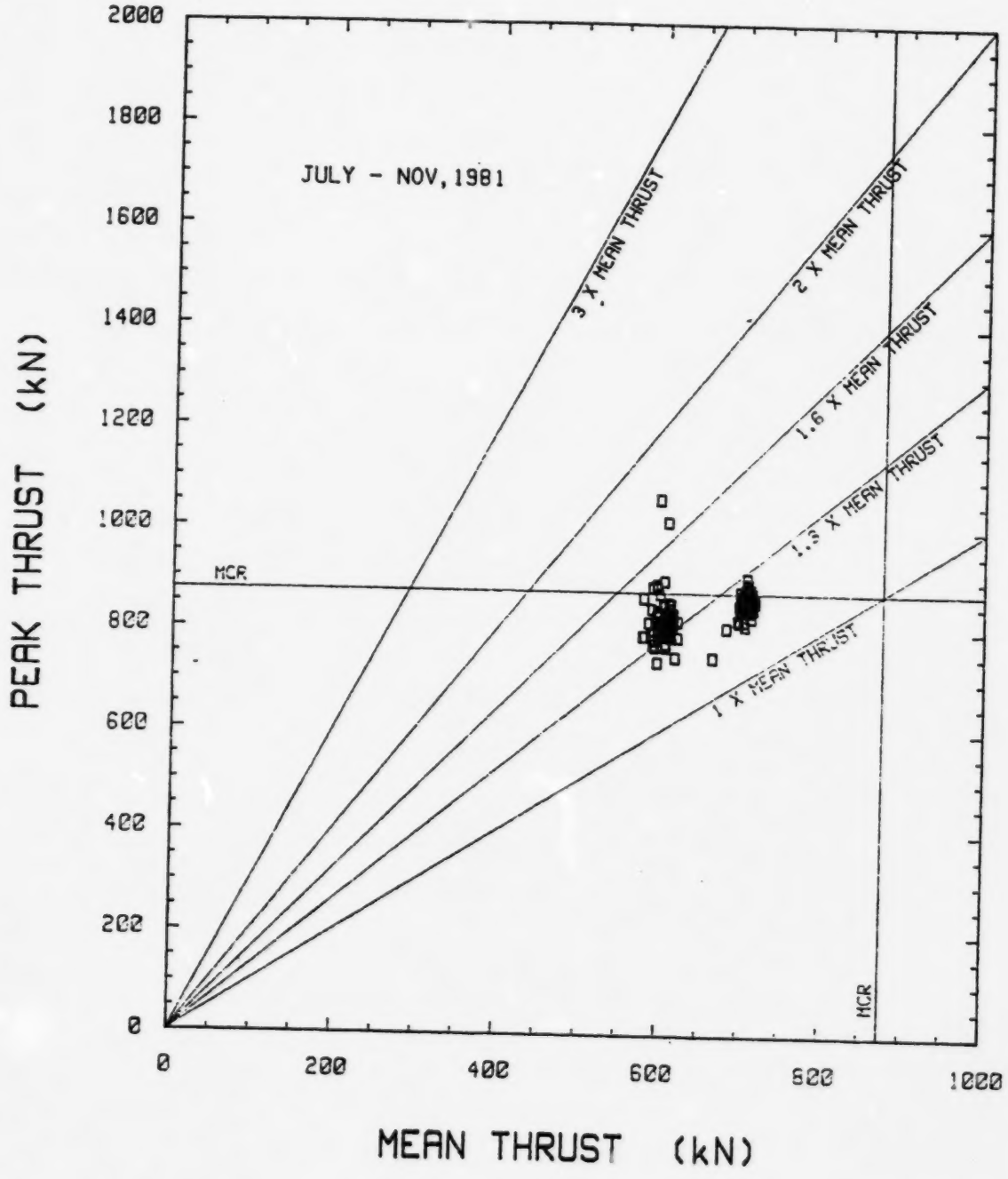

FIG. A4.9 SHAFT THRUST EXCURSIONS IN OPEN WATER

(Category 1.2 : OPEN WATER, ROUGH SEASTATE)

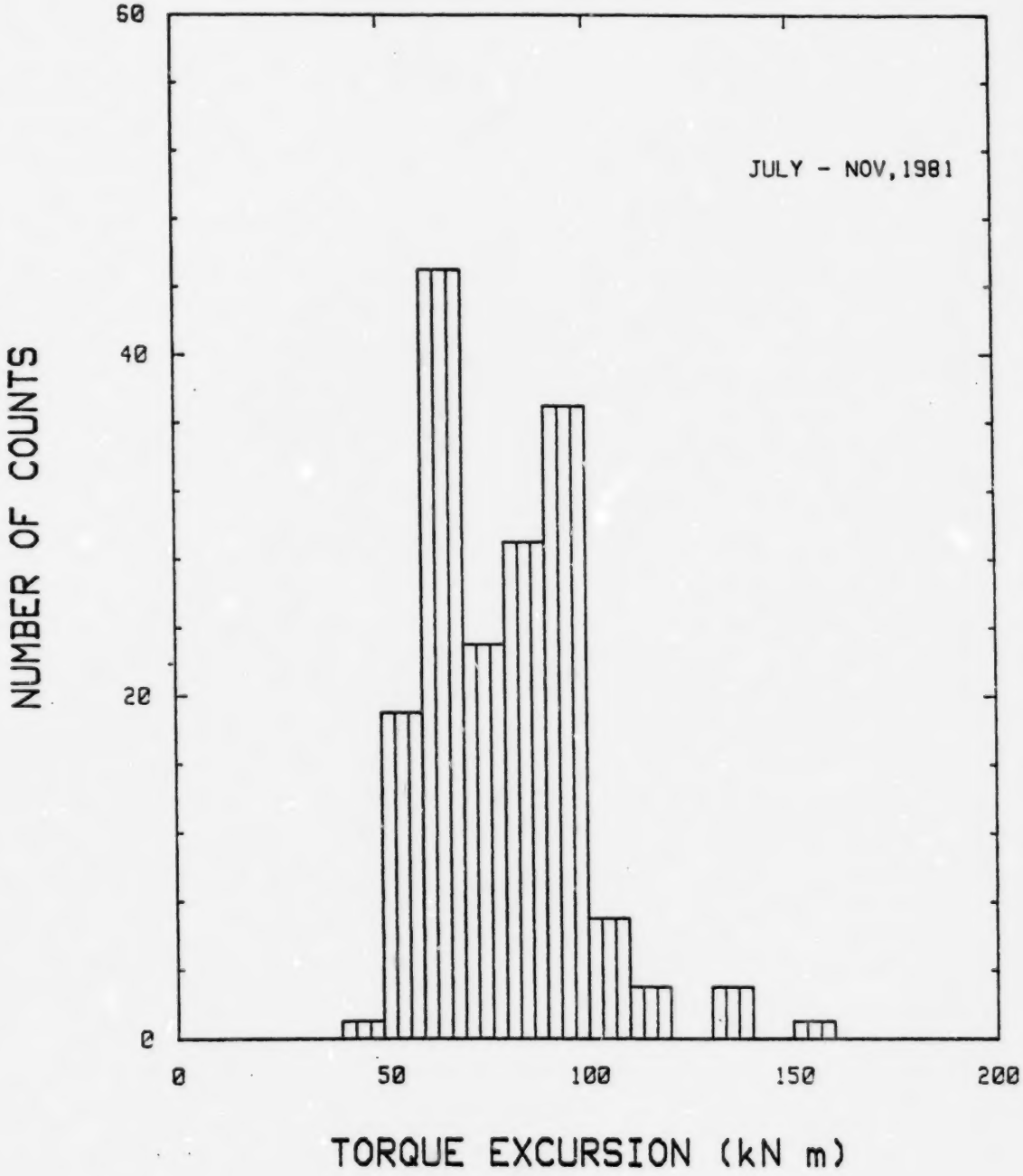

FIG. A4.10 SHAFT TORQUE EXCURSIONS IN OPEN WATER

(Category 1.2 : OPEN WATER, ROUGH SEASTATE)

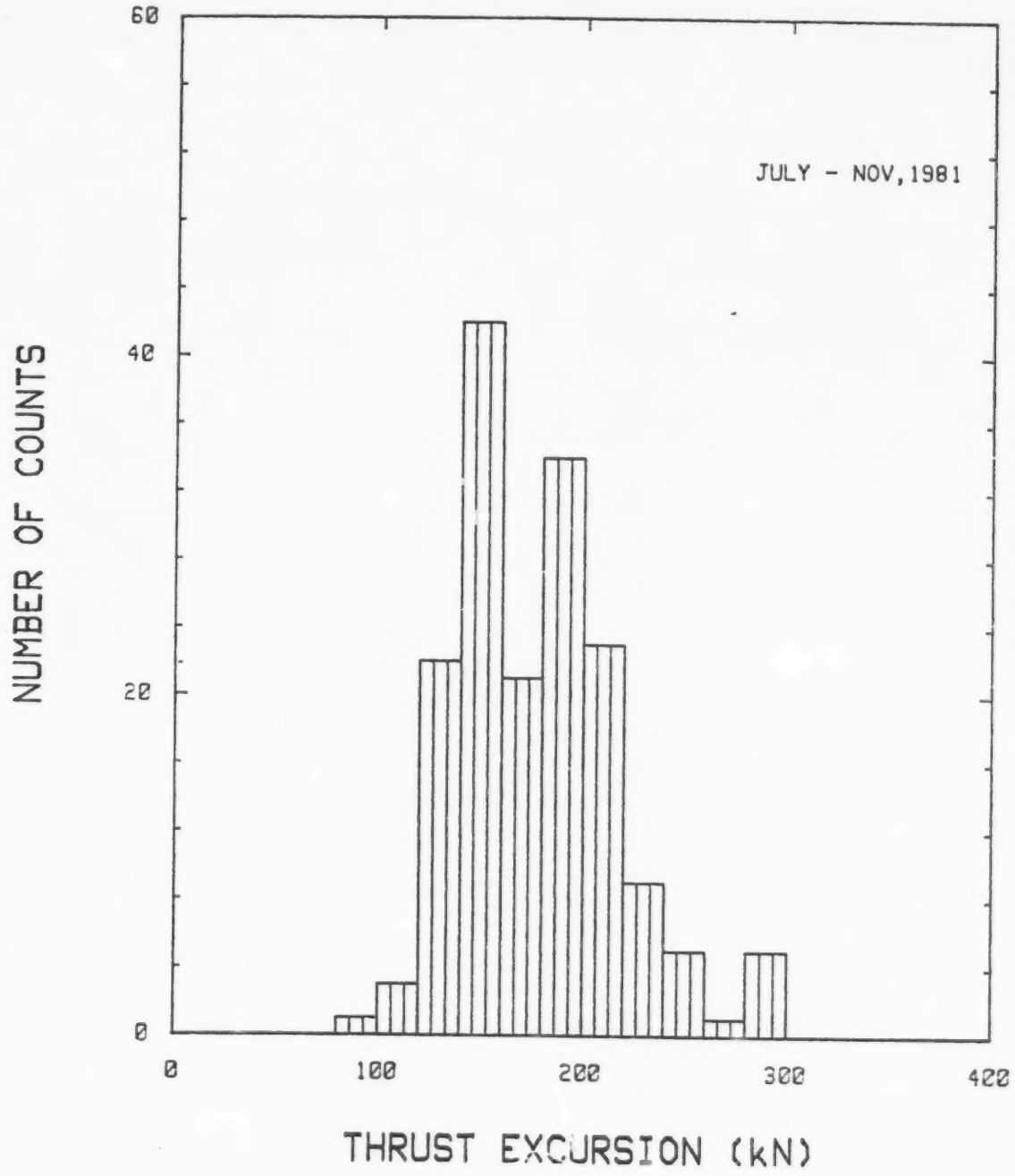

FIG. A4.11 SHAFT TORQUE EXCURSIONS IN OPEN WATER

(Category 1.2 : OPEN WATER, ROUGH SEASTATE)

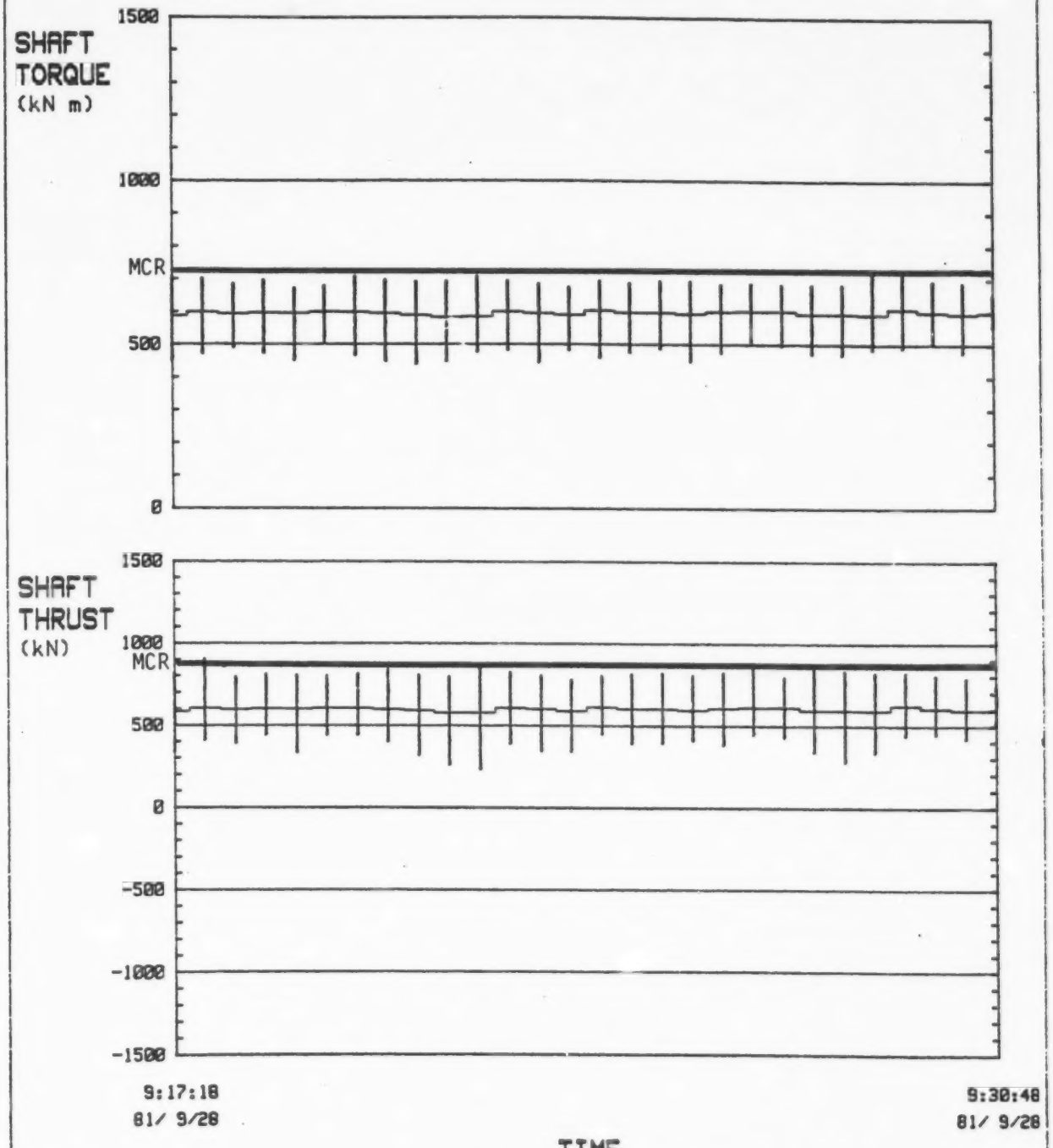

FIG. A4.12 PROPULSIVE PERFORMANCE RECORD

(OPEN WATER, ROUGH SEASTATE)

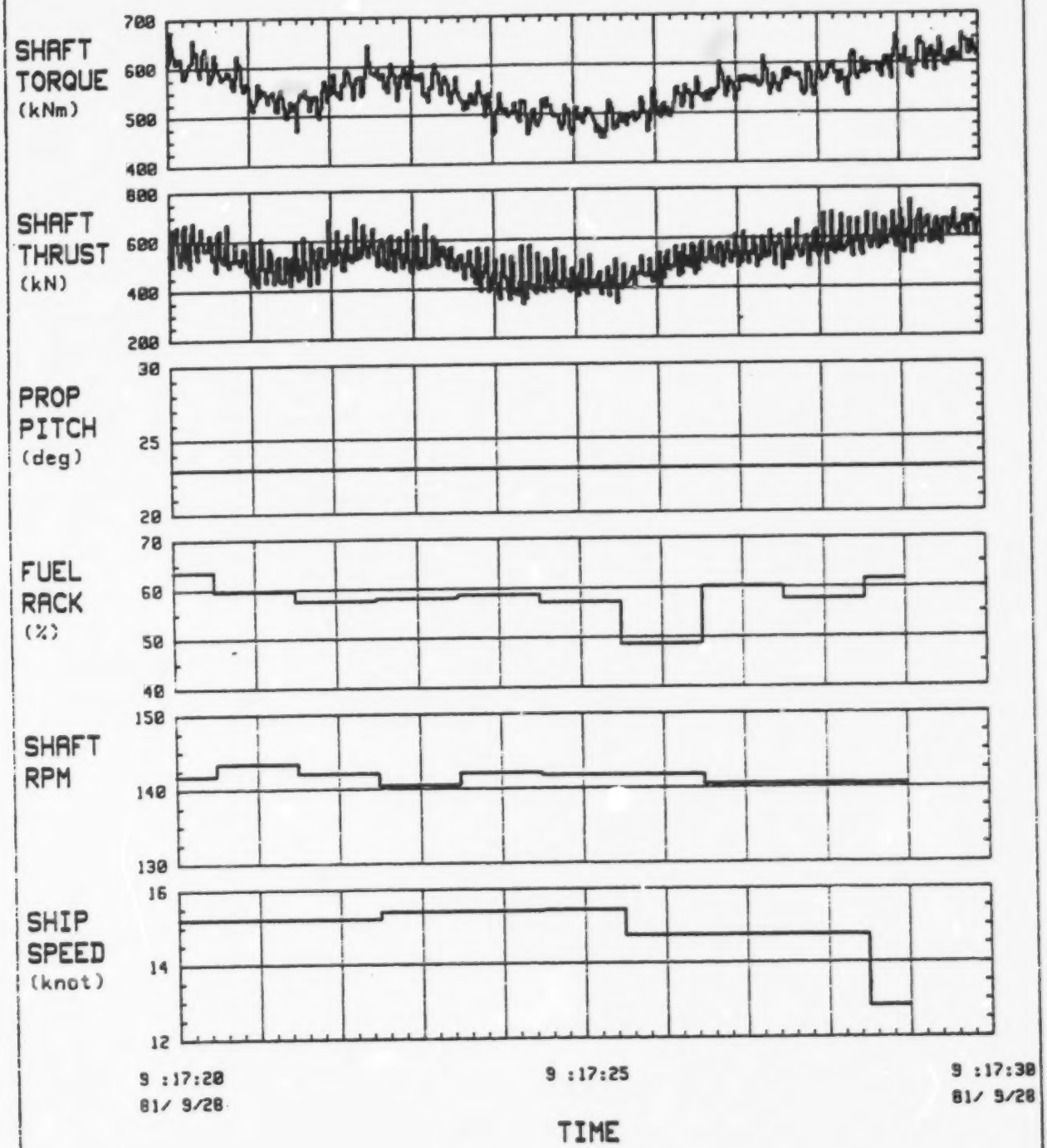

FIG. A4.13 PROPULSIVE PERFORMANCE RECORD

(OPEN WATER, ROUGH SEASTATE)

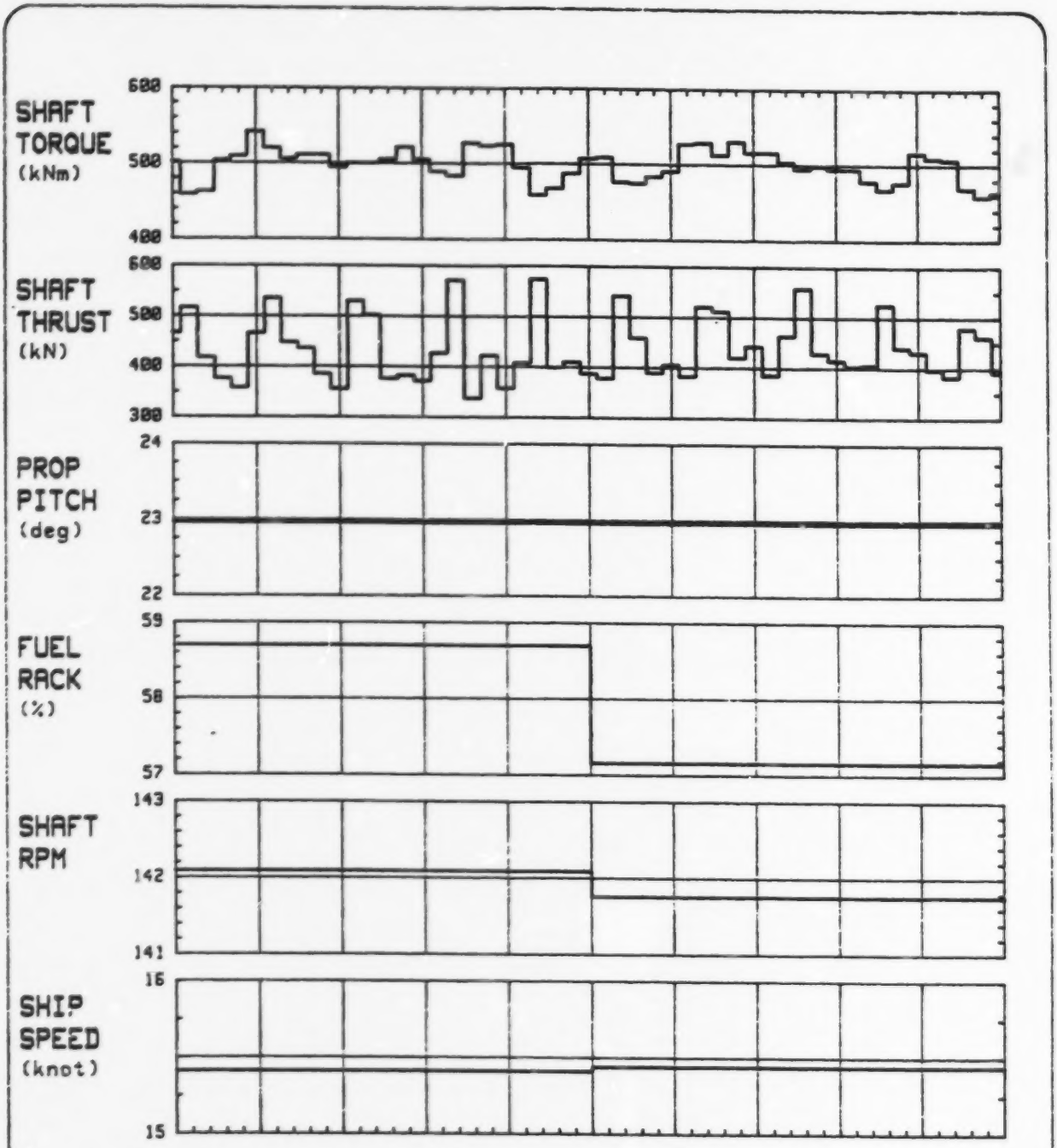

FIG. A4.14 PROPULSIVE PERFORMANCE RECORD

(OPEN WATER, ROUGH SEASTATE)

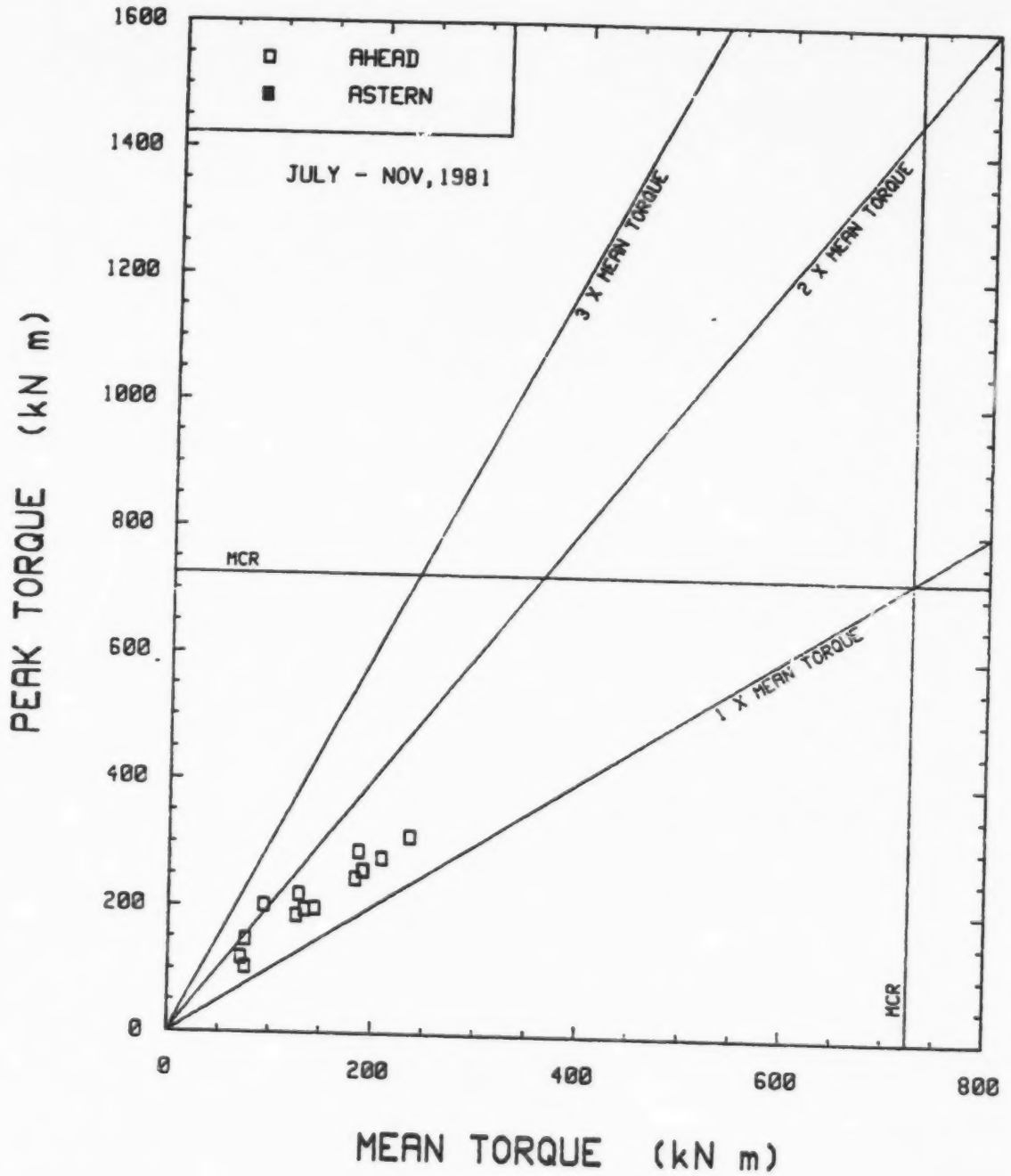

FIG. A4.15 ICE INDUCED SHAFT TORQUE EXCURSIONS

(Category 2.1 : CONTINUOUS, LEVEL HOMOGENEOUS ICE)

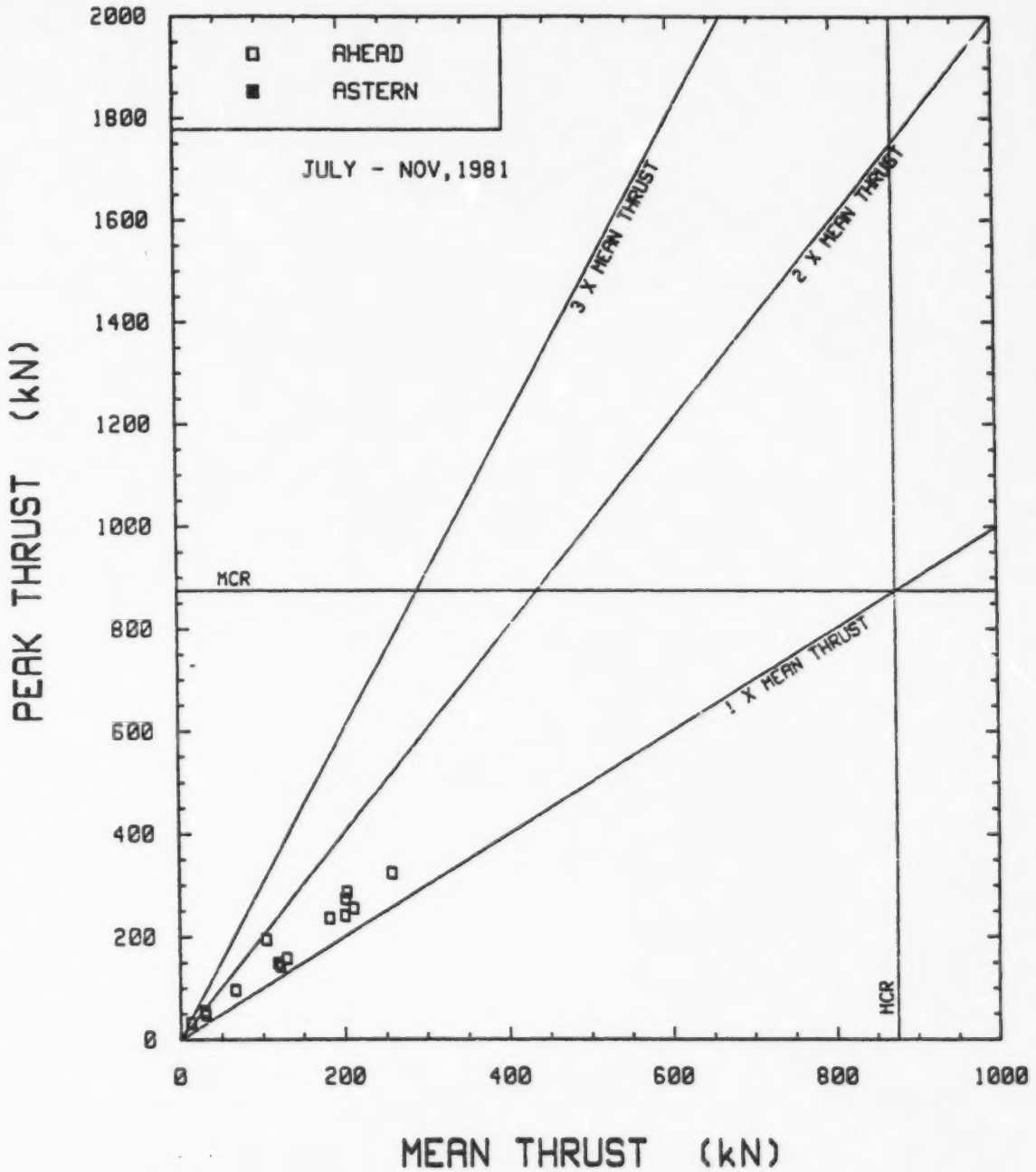

FIG. A4.16 ICE INDUCED SHAFT THRUST EXCURSIONS

(Category 2.1 : CONTINUOUS, LEVEL HOMOGENEOUS ICE)

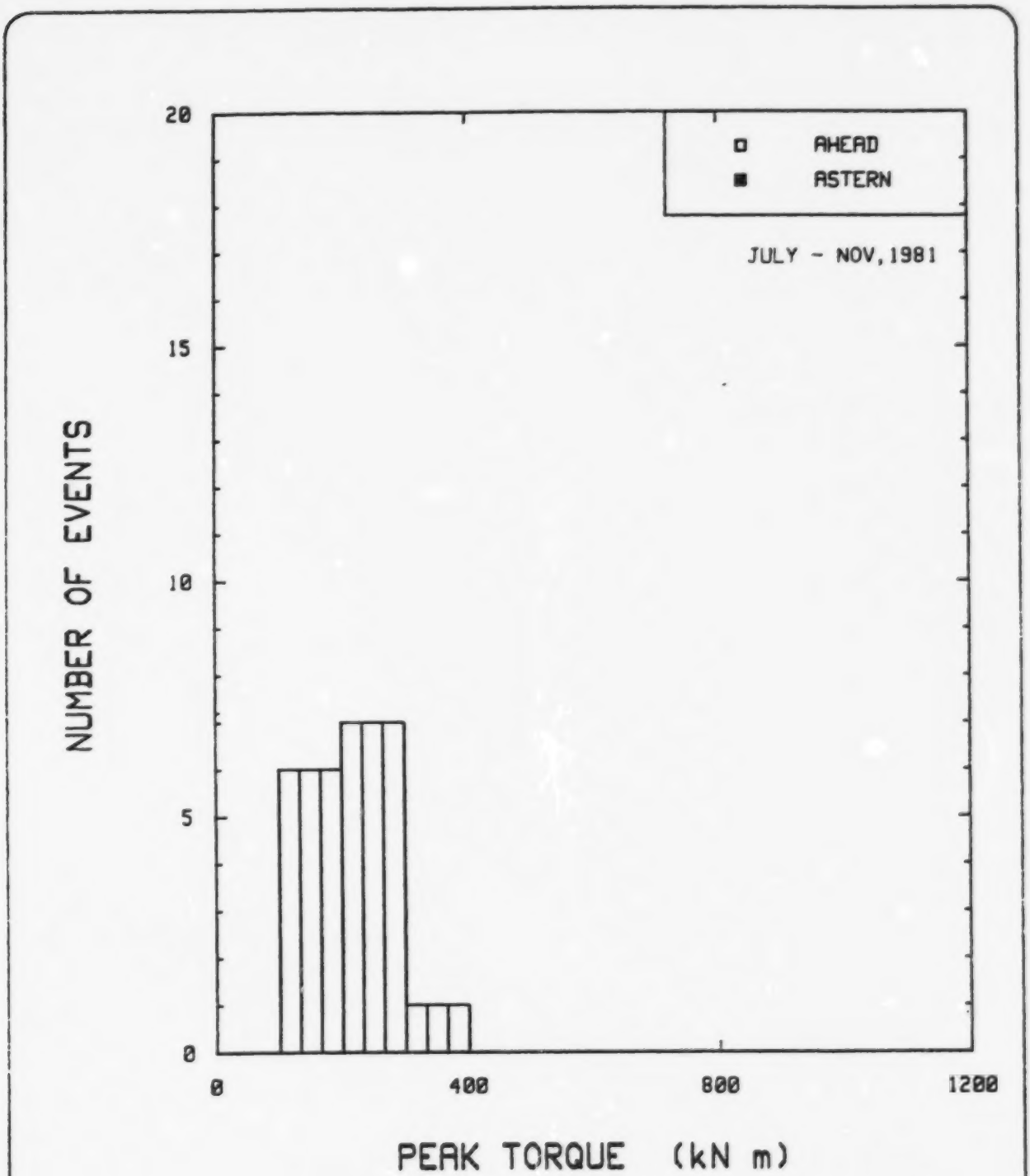

FIG. A4.17 MEASURED ICE INDUCED PEAK TORQUES.

(Category 2.1 : CONTINUOUS, LEVEL HOMOGENEOUS ICE)

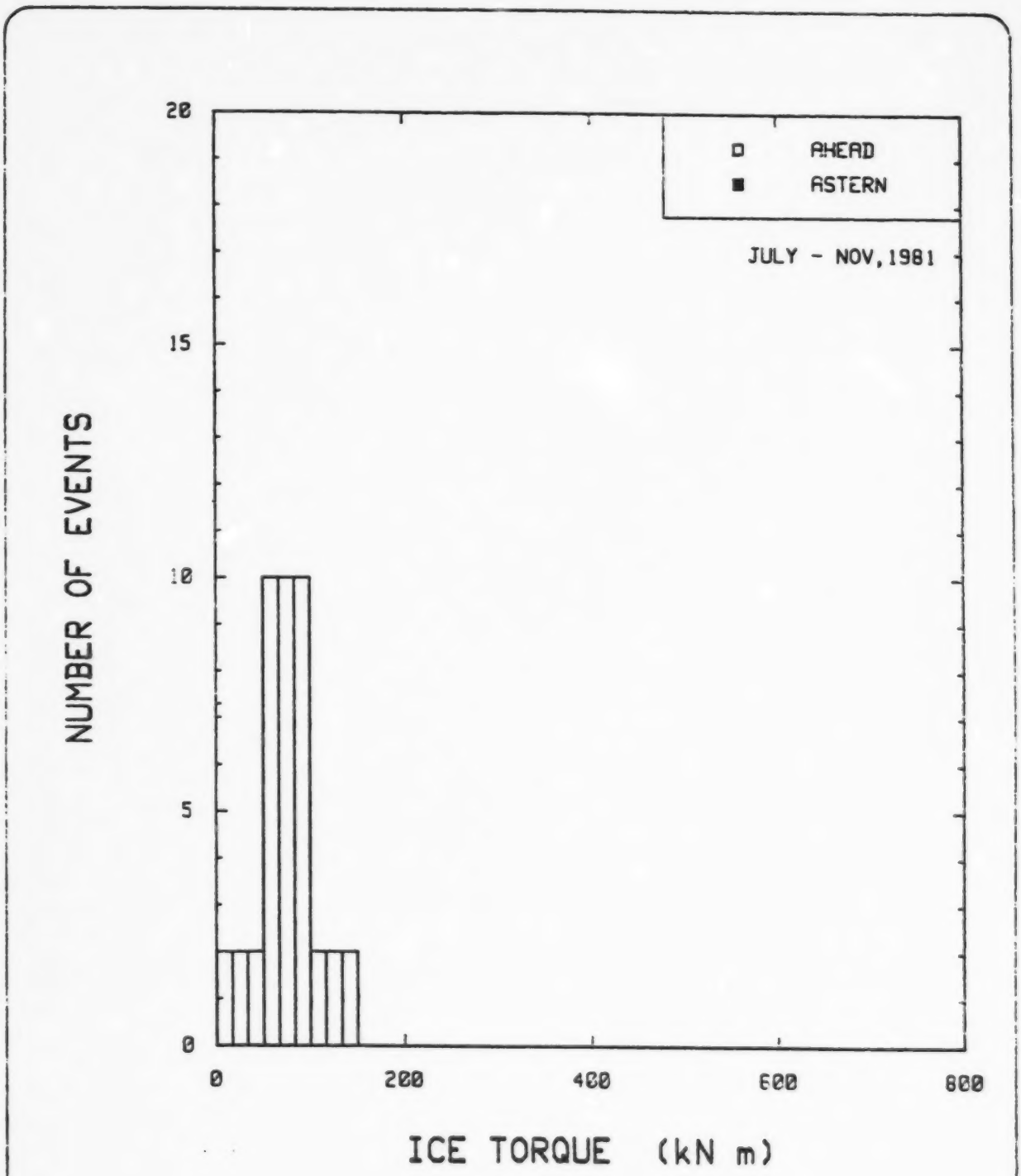

FIG. A4.18 MEASURED ICE TORQUES

(Category 2.1 : CONTINUOUS, LEVEL HOMOGENEOUS ICE)

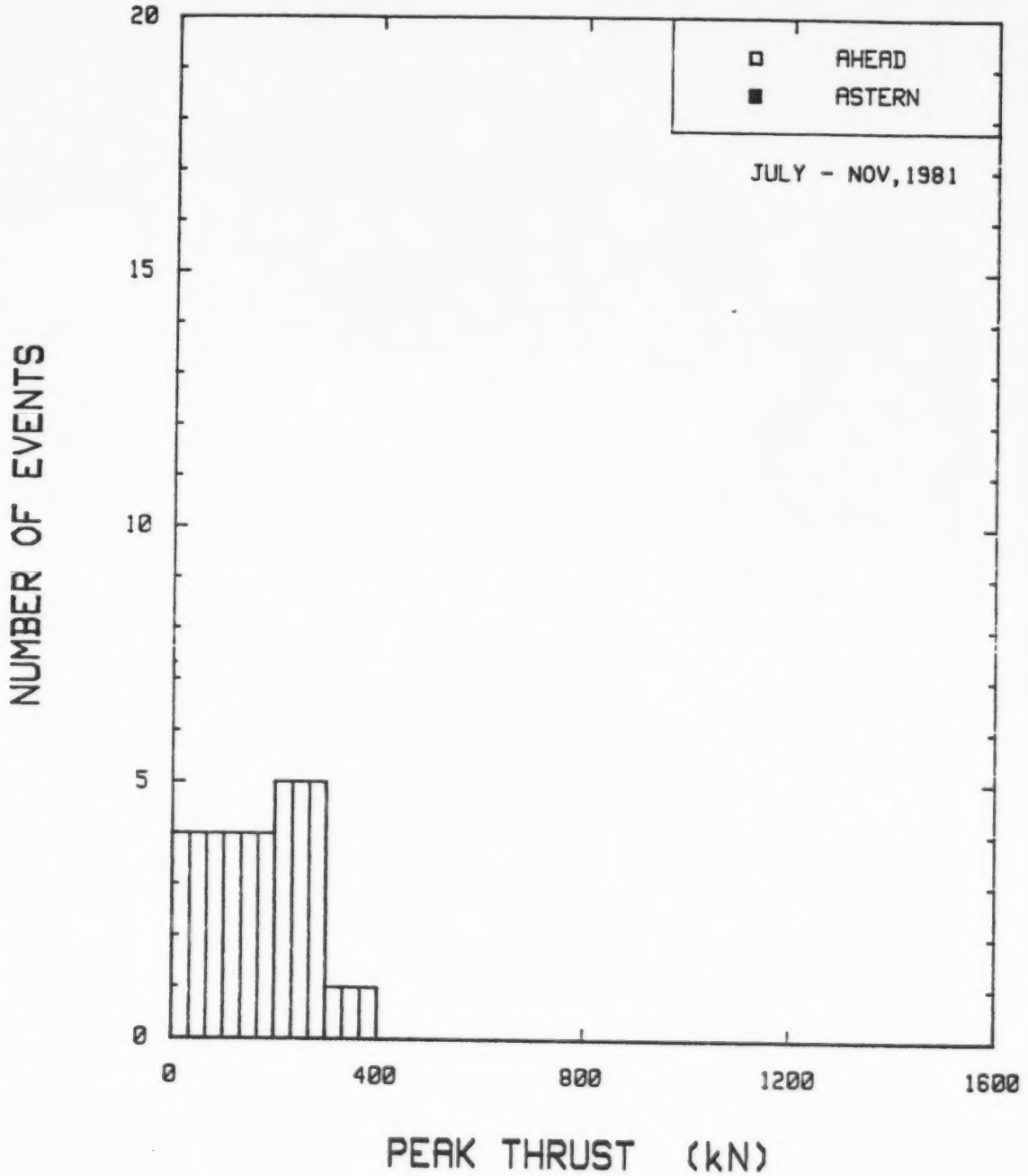

FIG. A4.19 MEASURED ICE INDUCED PEAK THRUSTS

(Category 2.1 : CONTINUOUS, LEVEL HOMOGENEOUS ICE)

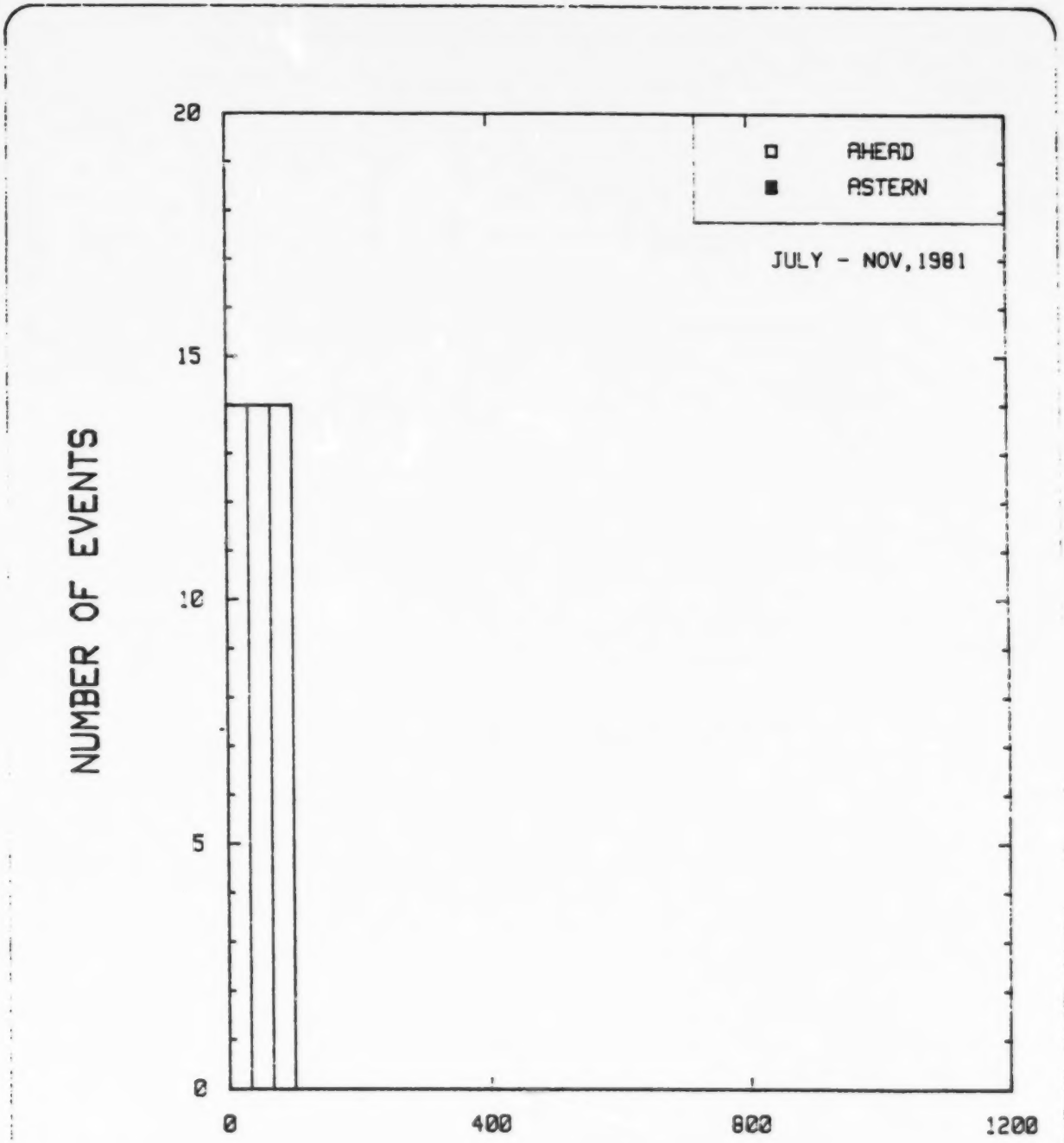

FIG. A4.20 MEASURED ICE THRUSTS

(Category 2.1 : CONTINUOUS, LEVEL HOMOGENEOUS ICE)

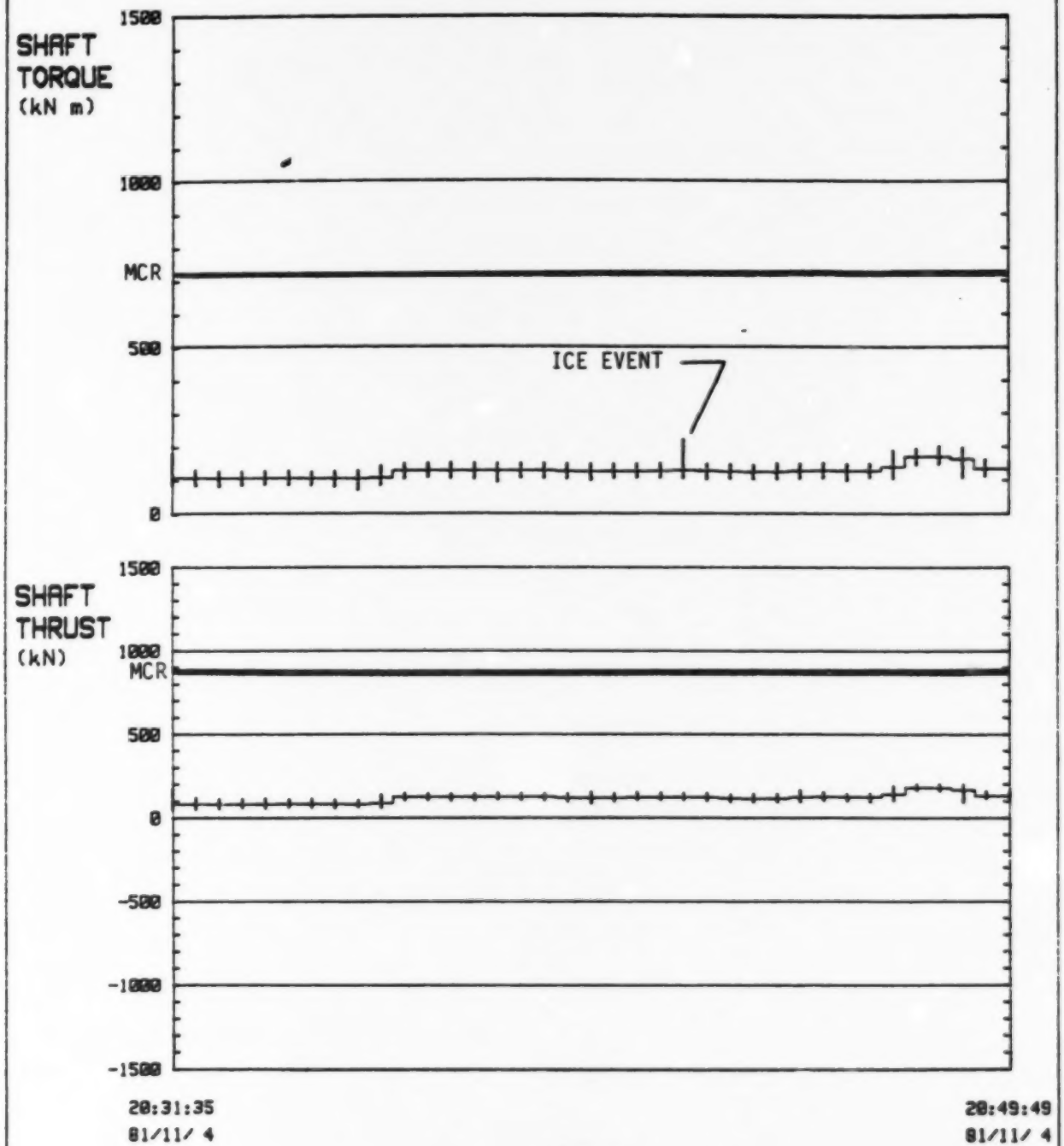

FIG. A4.21 PROPULSIVE PERFORMANCE RECORD

(CONTINUOUS ICE BREAKING, LEVEL HOMOGENEOUS ICE)

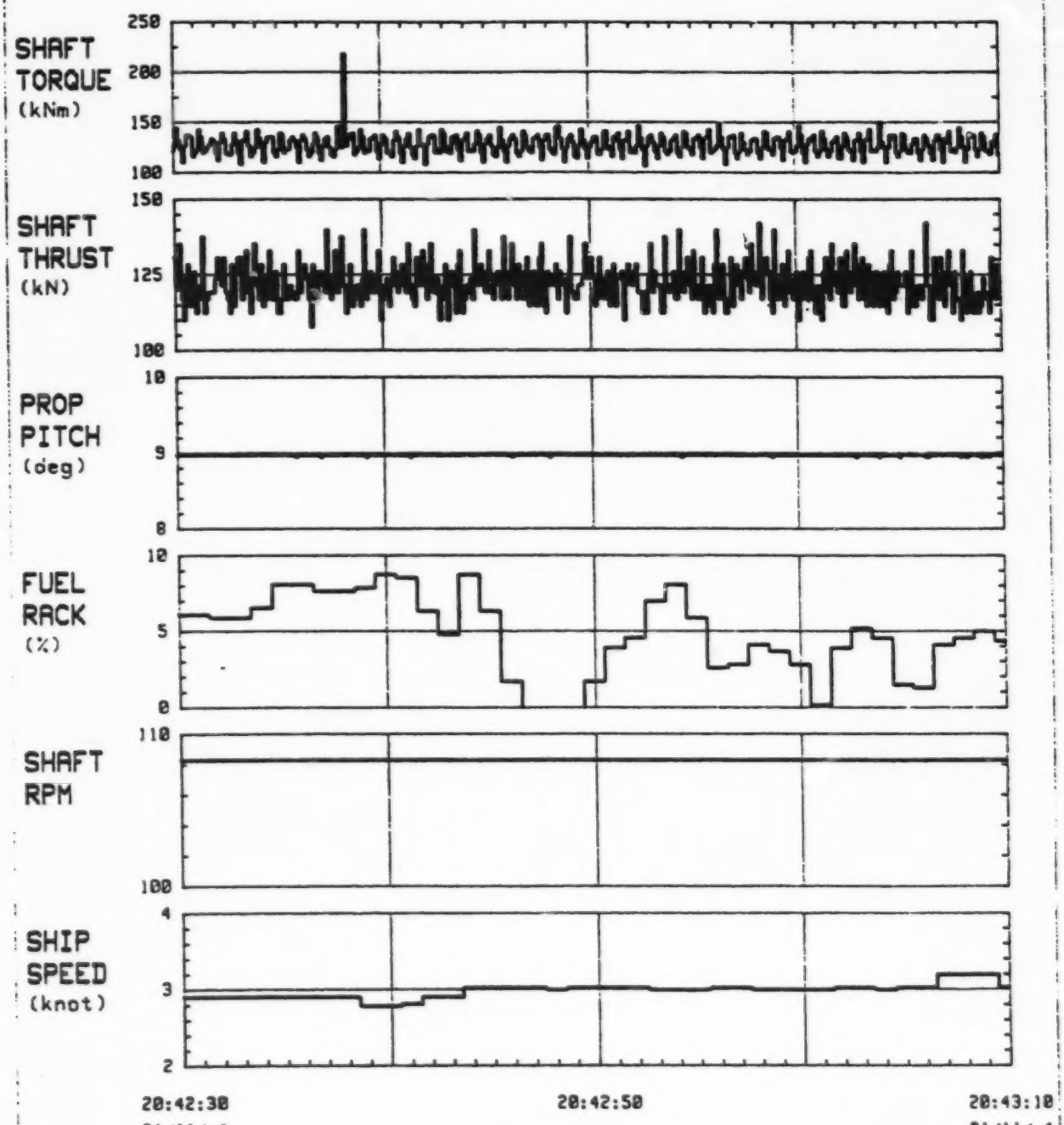

FIG. A4.22 PROPULSIVE PERFORMANCE RECORD

(CONTINUOUS ICE BREAKING, LEVEL HOMOGENEOUS ICE)

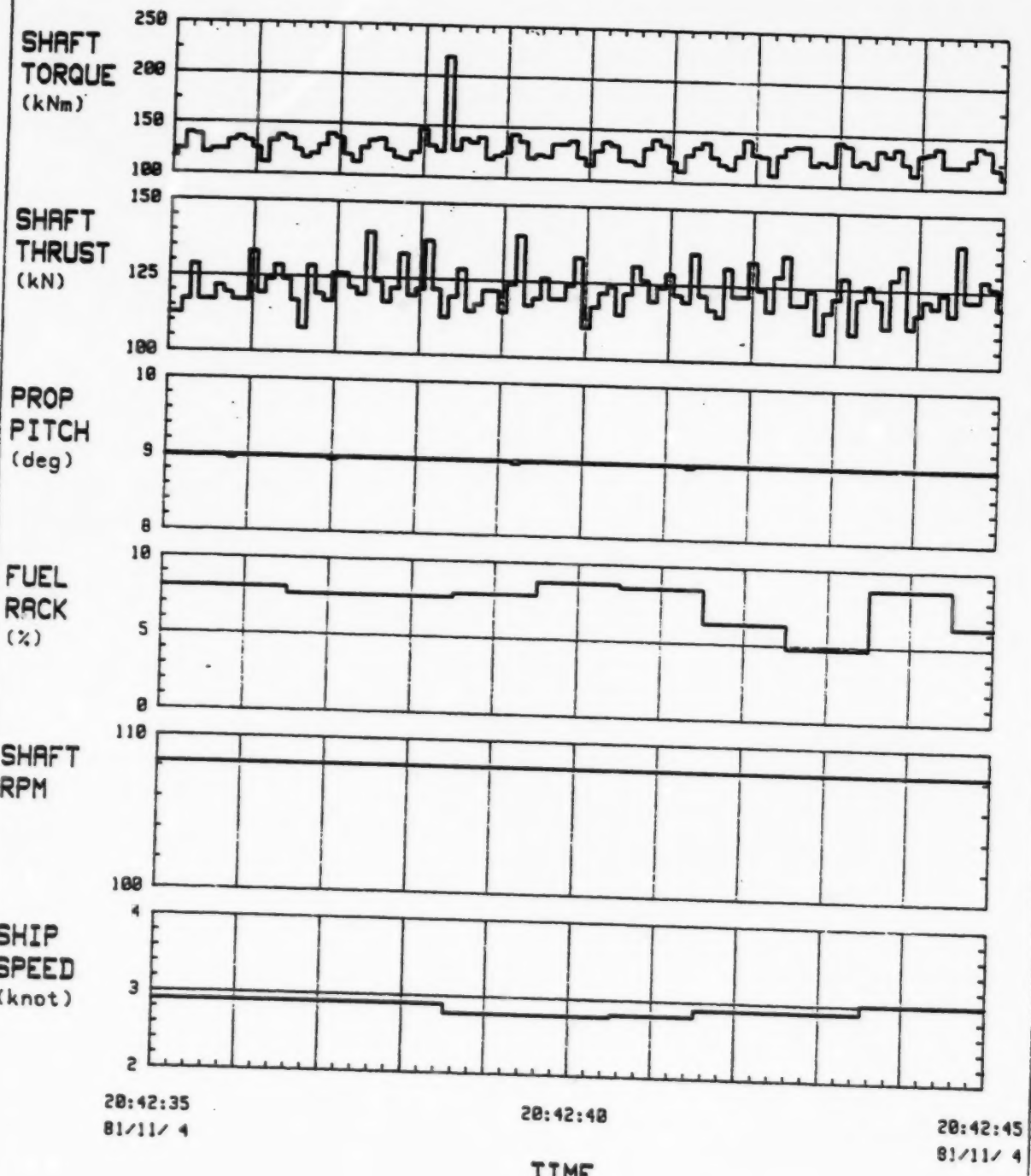

FIG. A4.23 PROPULSIVE PERFORMANCE RECORD

(CONTINUOUS ICE BREAKING, LEVEL HOMOGENEOUS ICE)

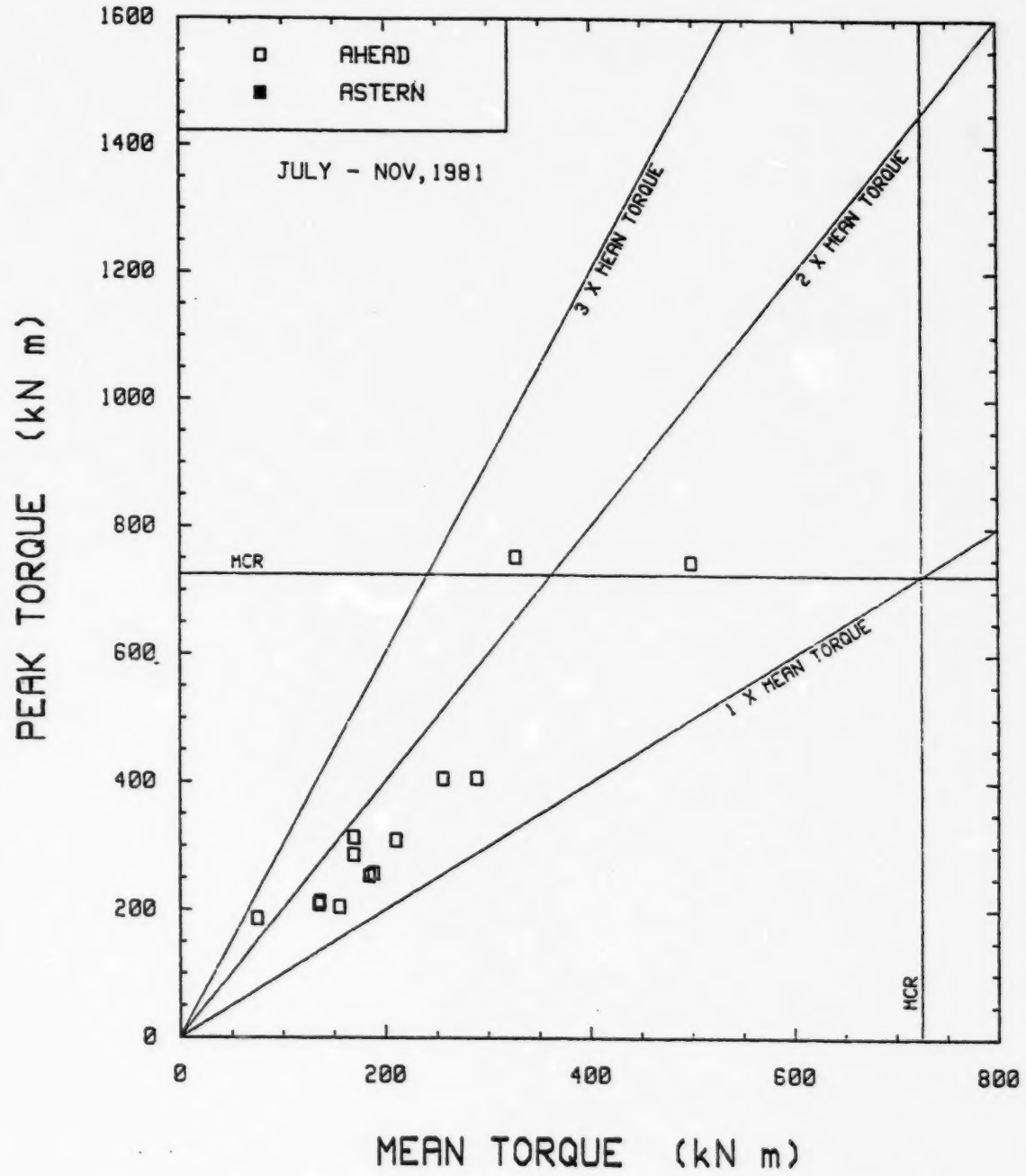

FIG. A4.24 ICE INDUCED SHAFT TORQUE EXCURSIONS

(Category 2.2 : CONTINUOUS, UNIFORM MIXED ICE)

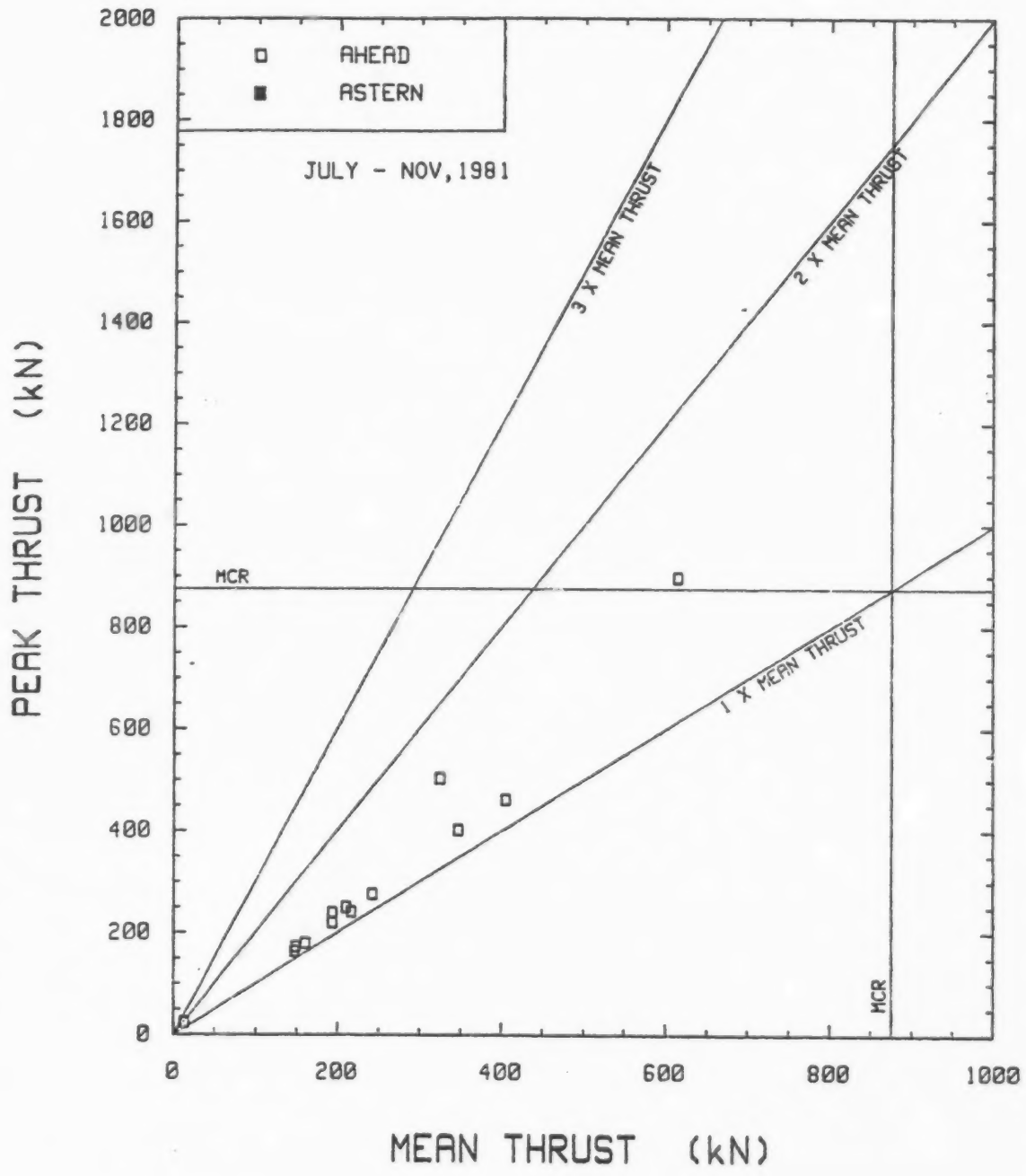

FIG. A4.25 ICE INDUCED SHAFT THRUST EXCURSIONS

(Category 2.2 : CONTINUOUS, UNIFORM MIXED ICE)

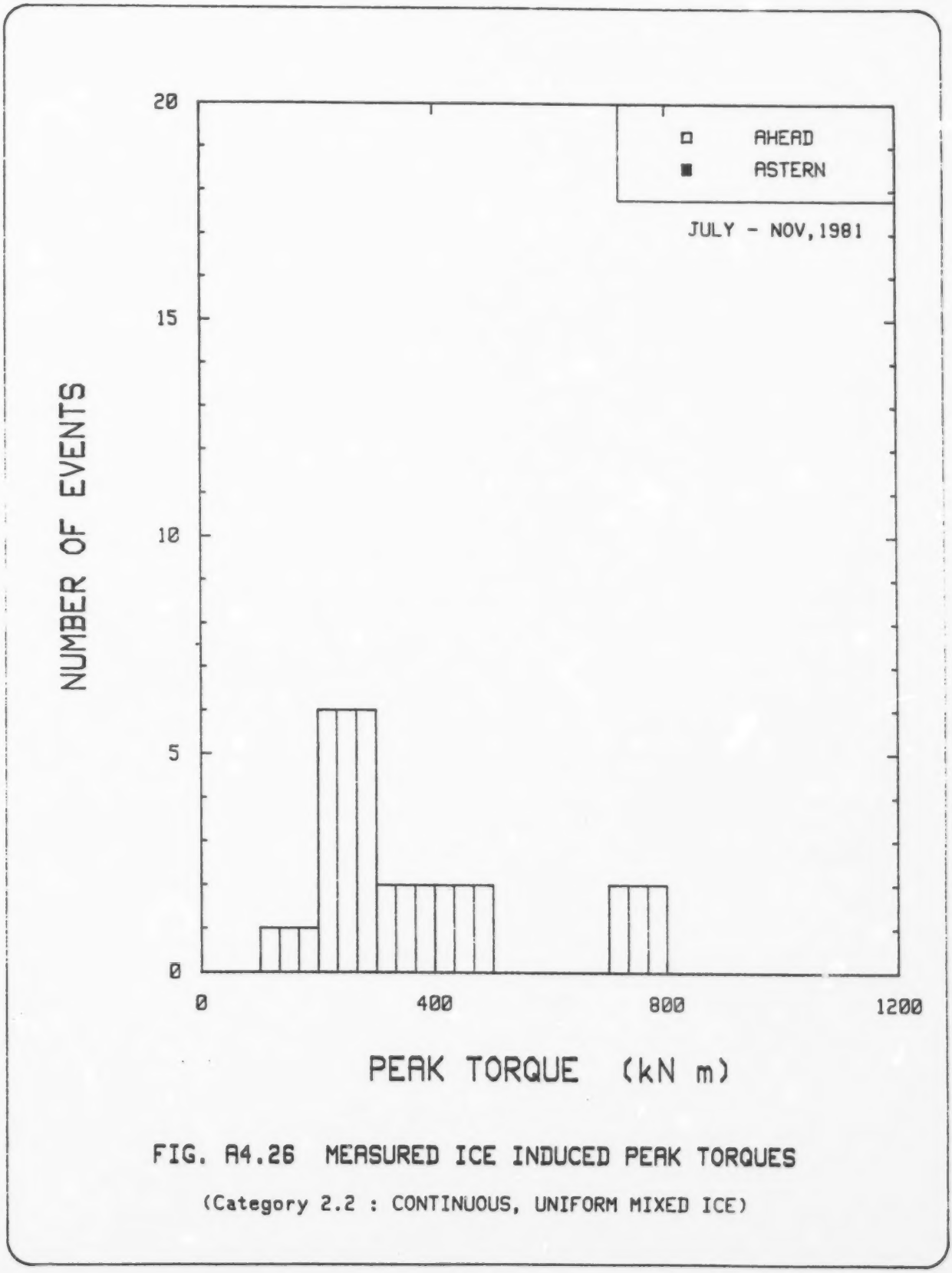

FIG. A4.26 MEASURED ICE INDUCED PEAK TORQUES

(Category 2.2 : CONTINUOUS, UNIFORM MIXED ICE)

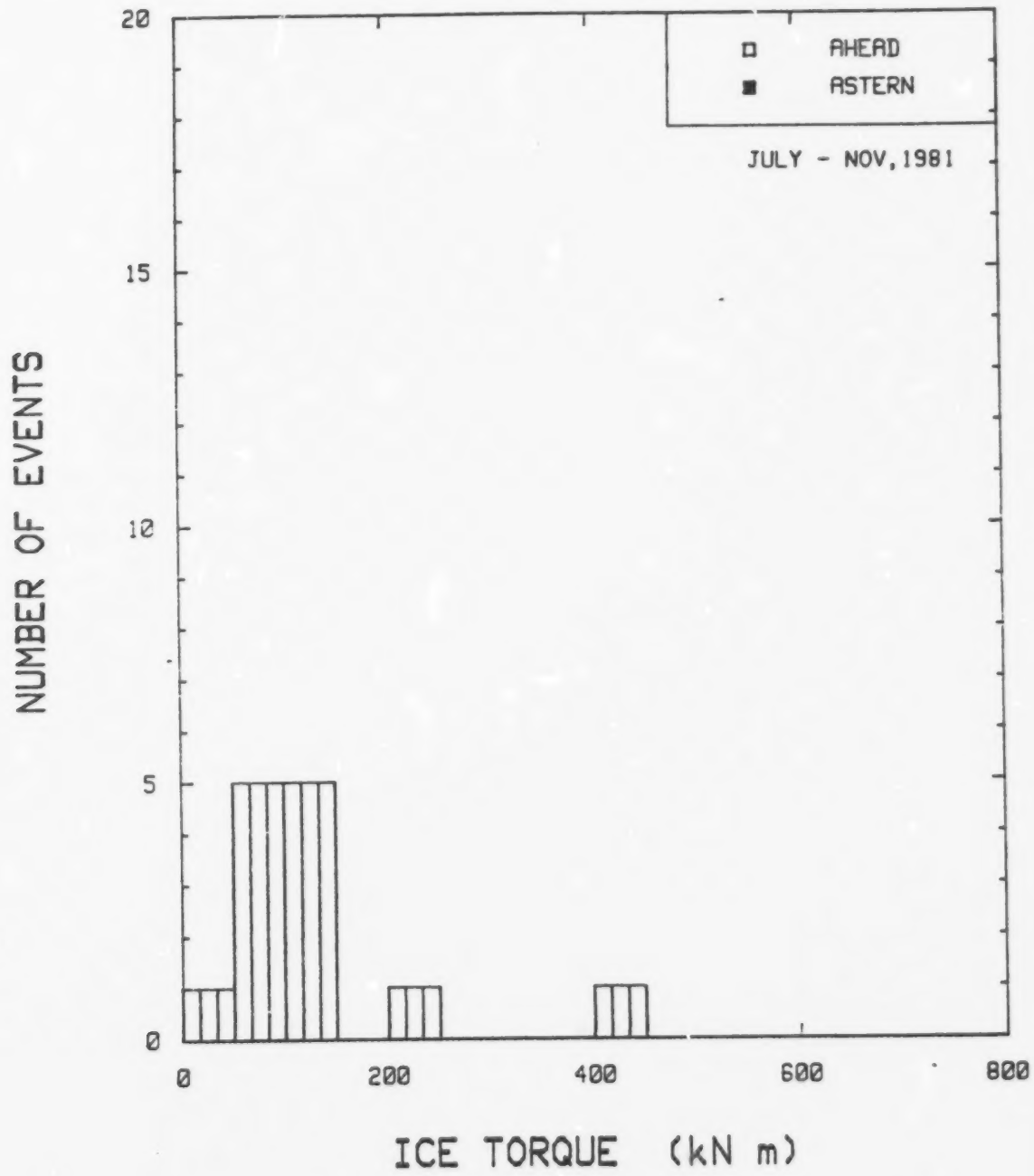

FIG. A4.27 MEASURED ICE TORQUES

(Category 2.2 : CONTINUOUS, UNIFORM MIXED ICE)

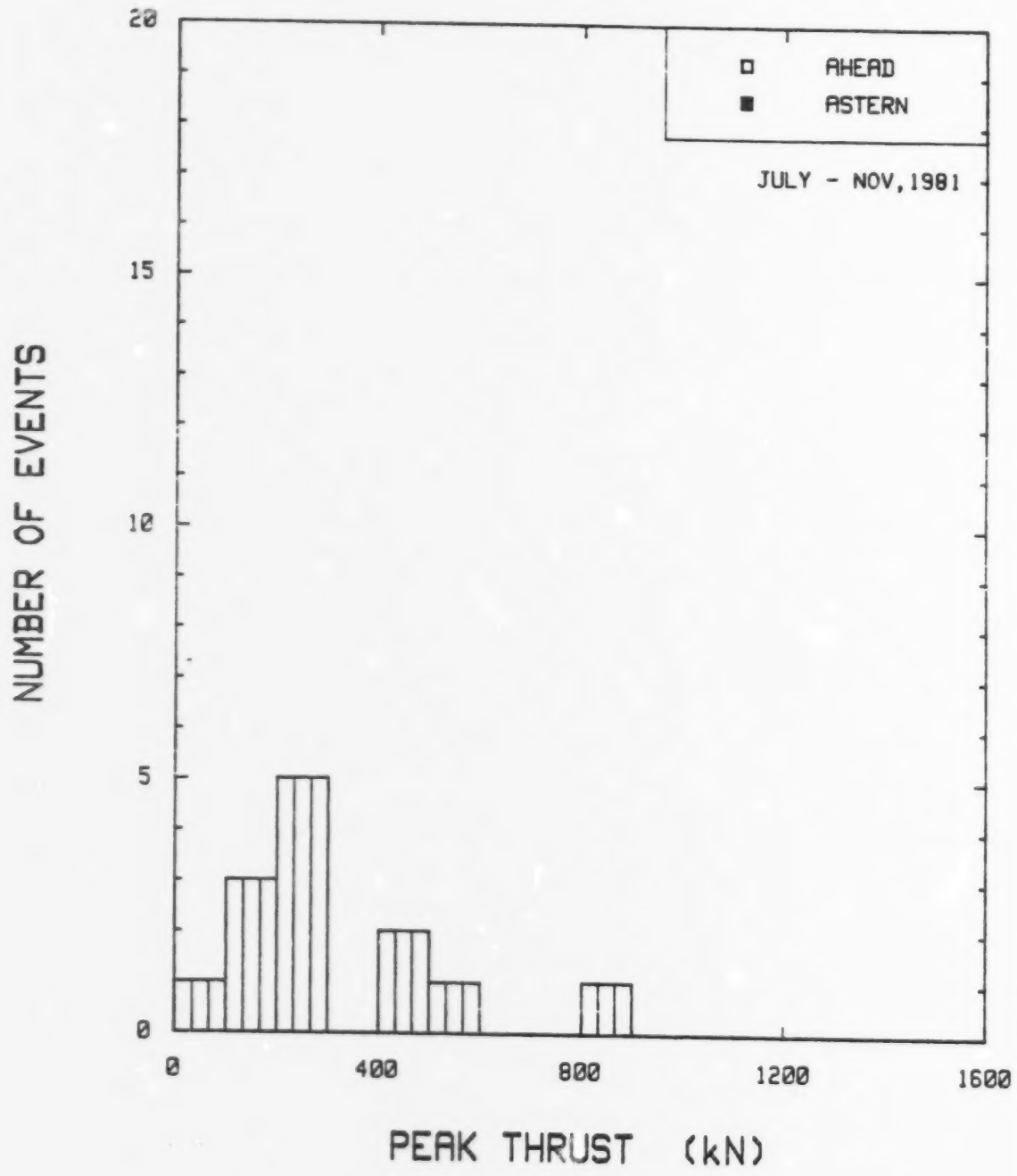

FIG. A4.28 MEASURED ICE INDUCED PEAK THRUSTS

(Category 2.2 : CONTINUOUS, UNIFORM MIXED ICE)

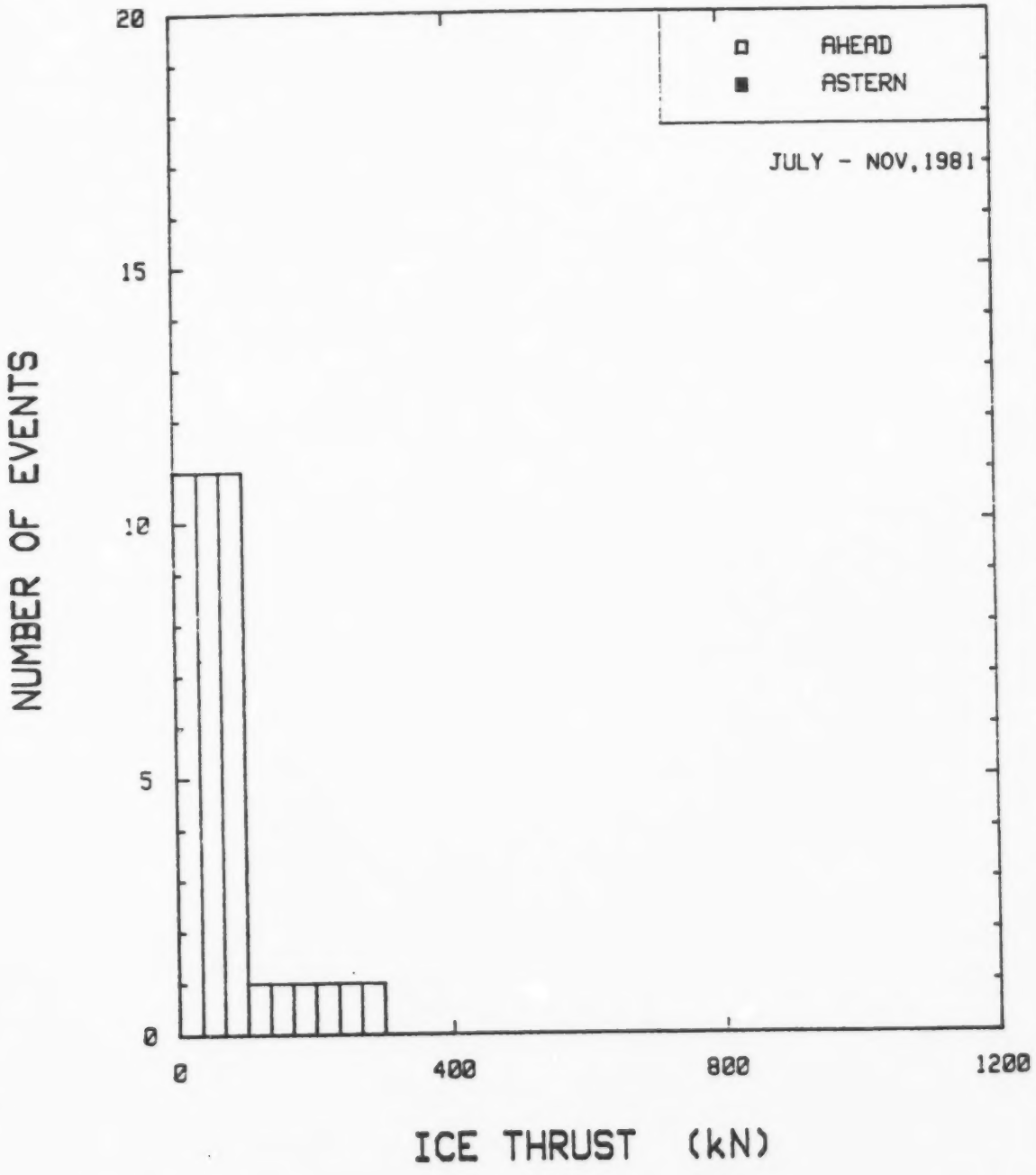

FIG. A4.29 MEASURED ICE THRUSTS

(Category 2.2 : CONTINUOUS, UNIFORM MIXED ICE)

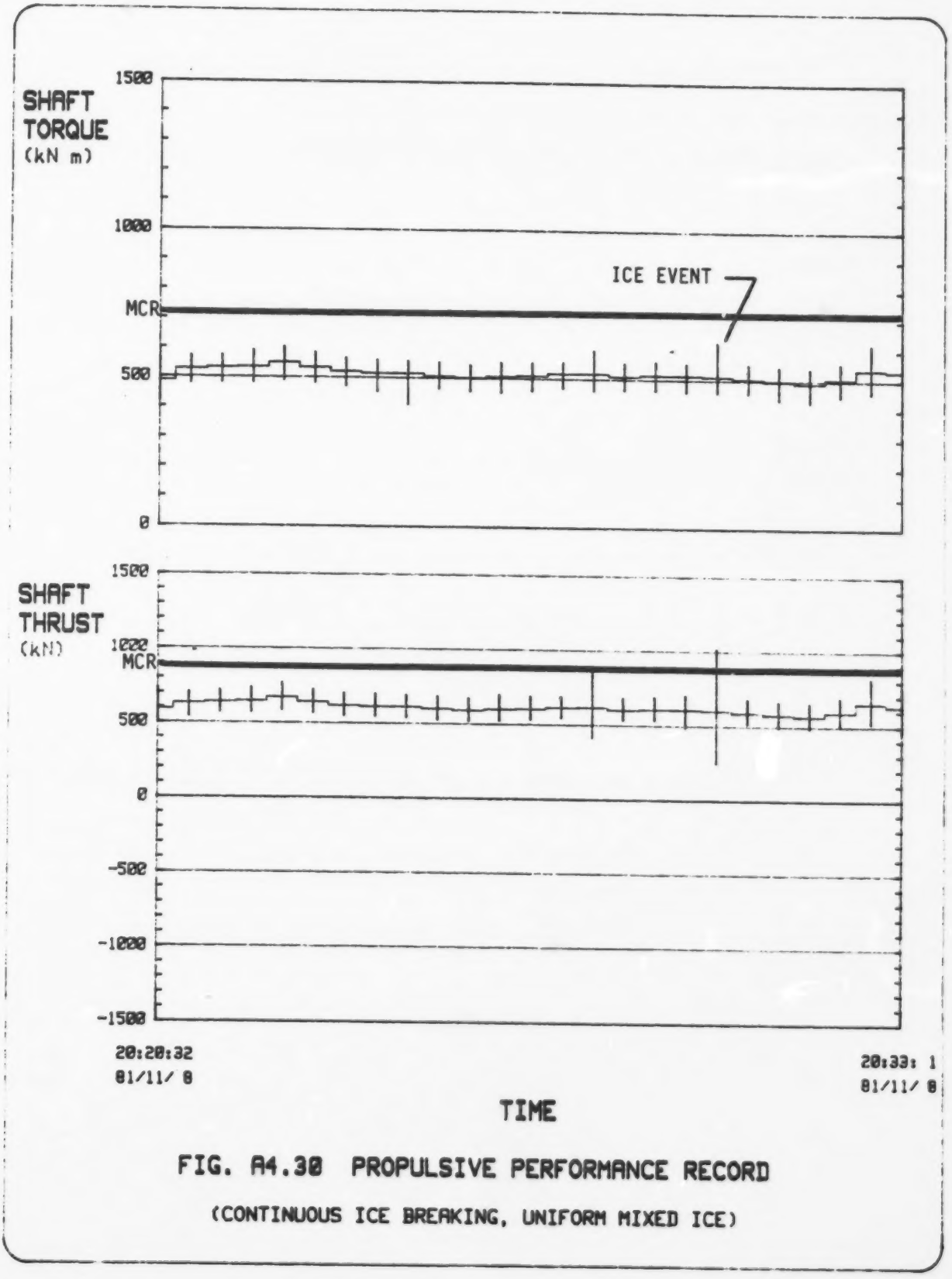

FIG. A4.30 PROPULSIVE PERFORMANCE RECORD

(CONTINUOUS ICE BREAKING, UNIFORM MIXED ICE)

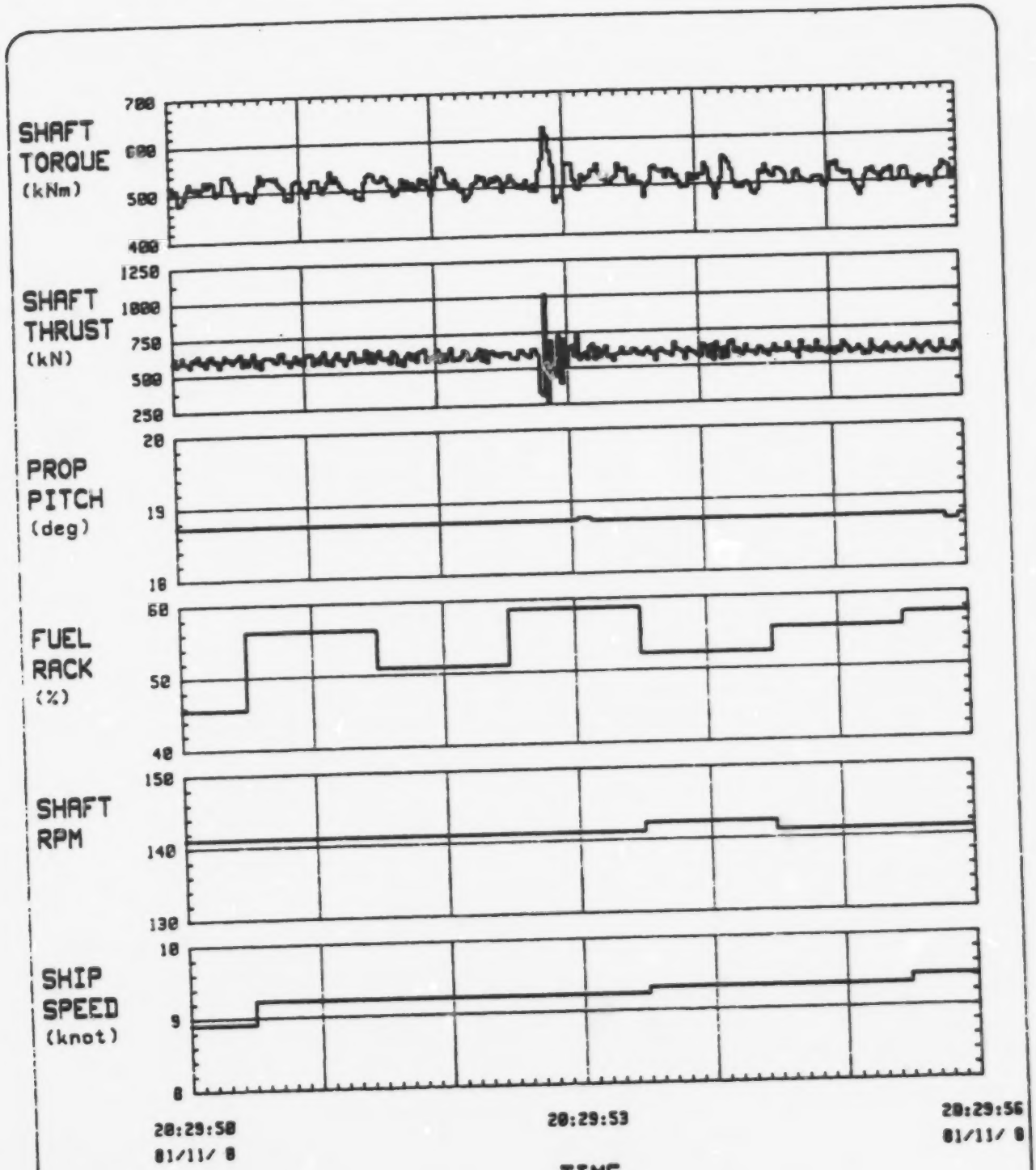

FIG. A4.31 PROPULSIVE PERFORMANCE RECORD

(CONTINUOUS ICE BREAKING, UNIFORM MIXED ICE)

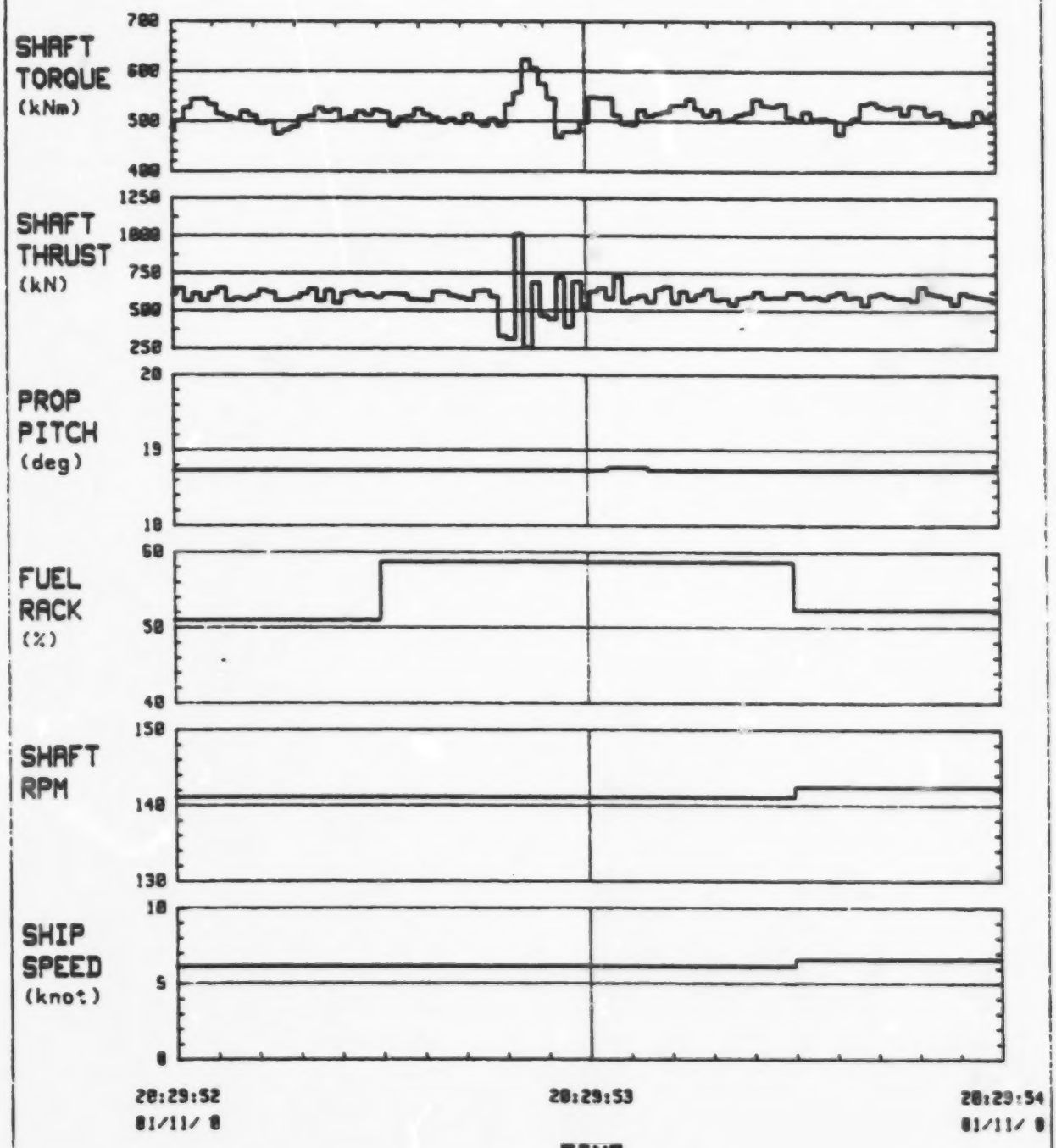

FIG. A4.32 PROPULSIVE PERFORMANCE RECORD

(CONTINUOUS ICE BREAKING, UNIFORM MIXED ICE)

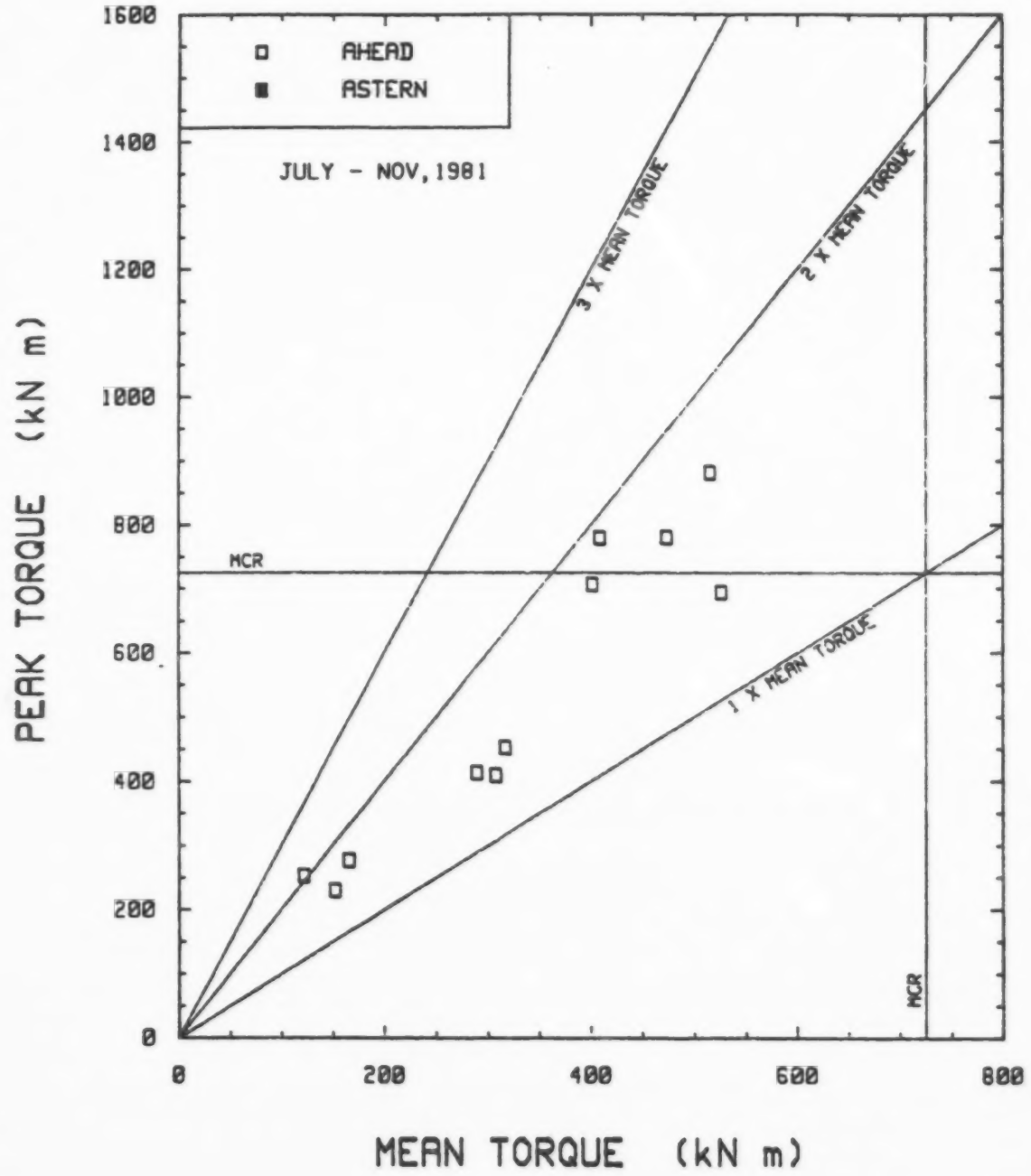

FIG. A4.33 ICE INDUCED SHAFT TORQUE EXCURSIONS

(Category 2.3 : CONTINUOUS, BROKEN CHANNEL)

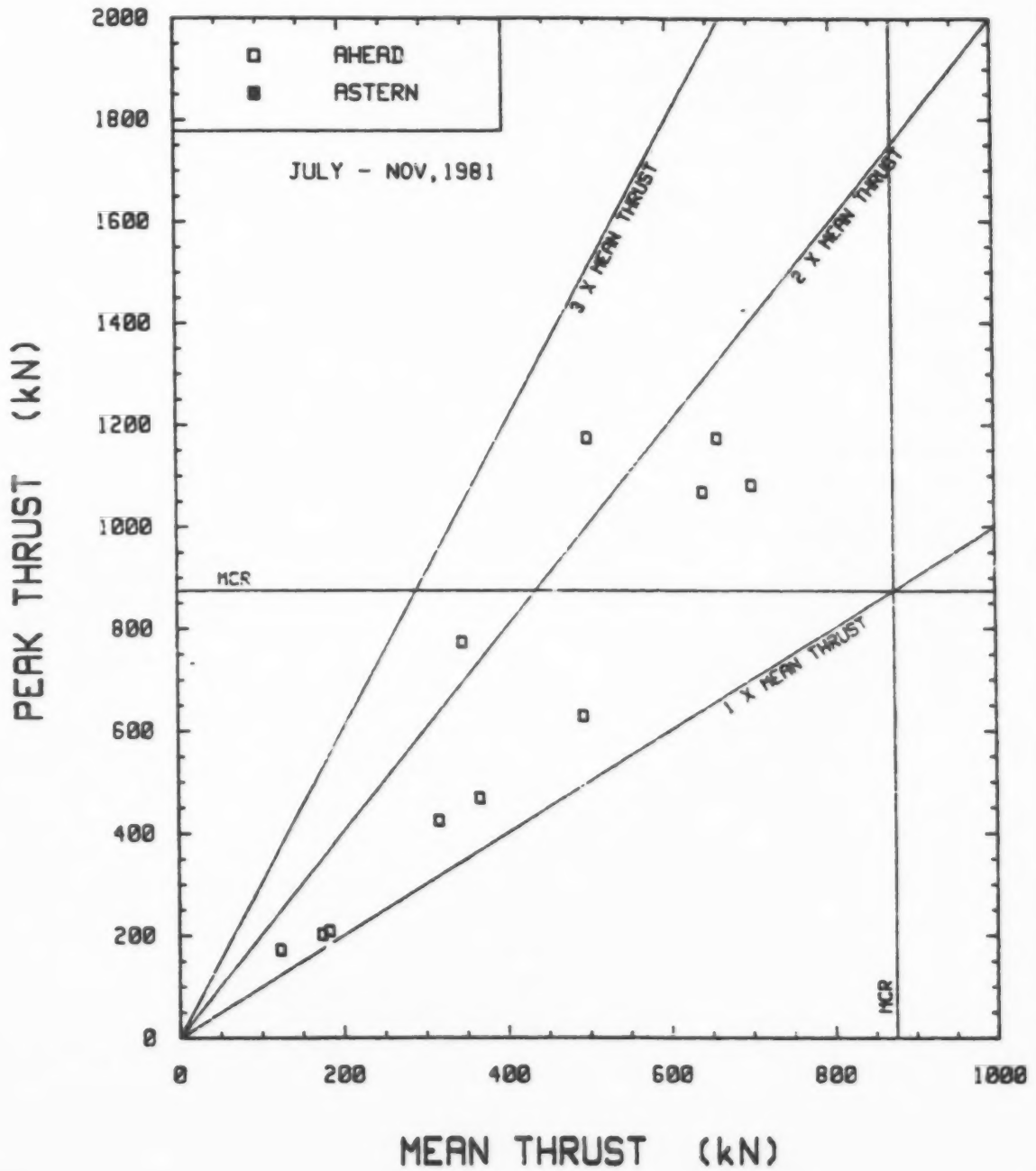

FIG. A4.34 ICE INDUCED SHAFT THRUST EXCURSIONS

(Category 2.3 : CONTINUOUS, BROKEN CHANNEL)

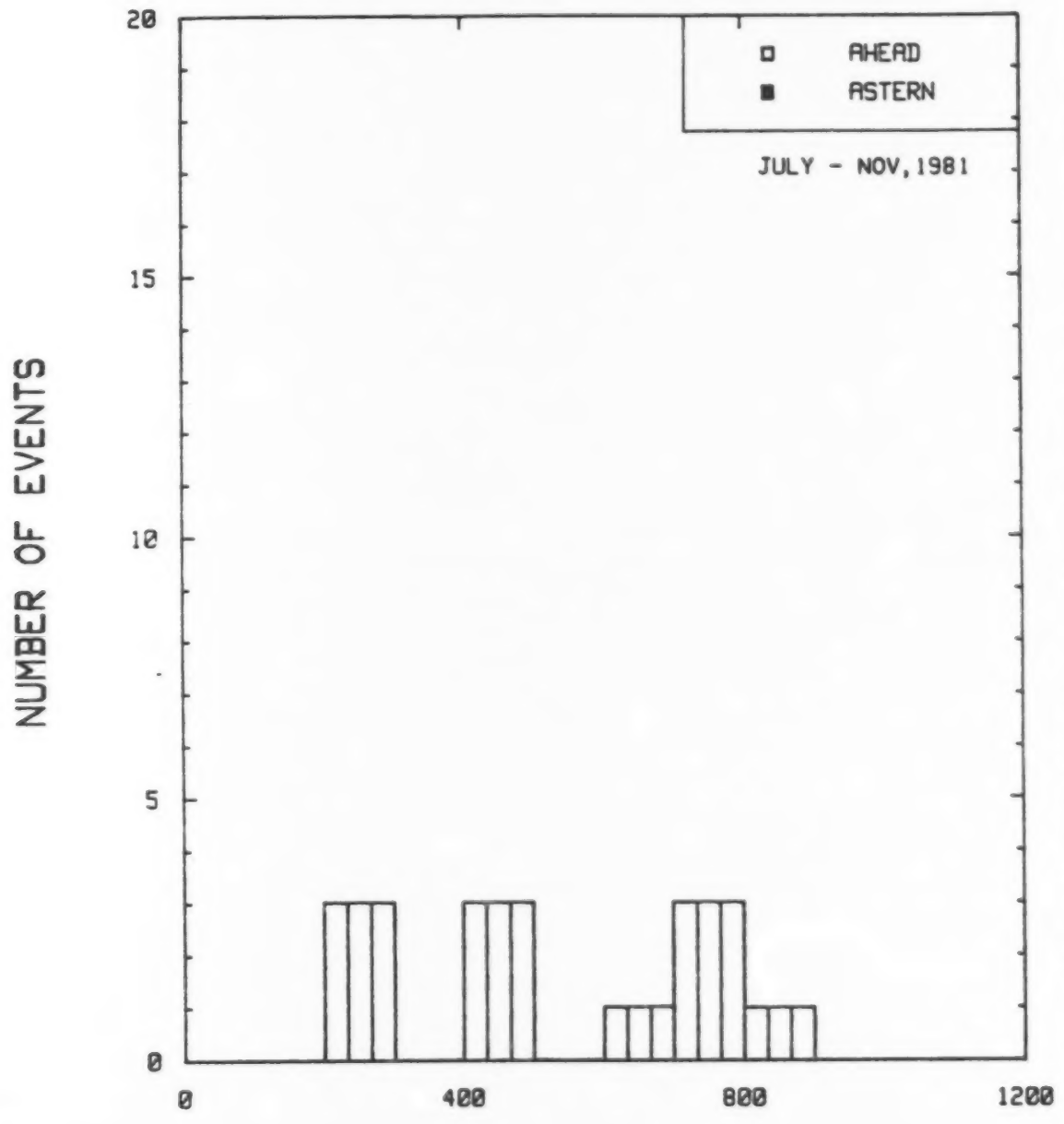

FIG. A4.35 MEASURED ICE INDUCED PEAK TORQUES

(Category 2.3 : CONTINUOUS, BROKEN CHANNEL)

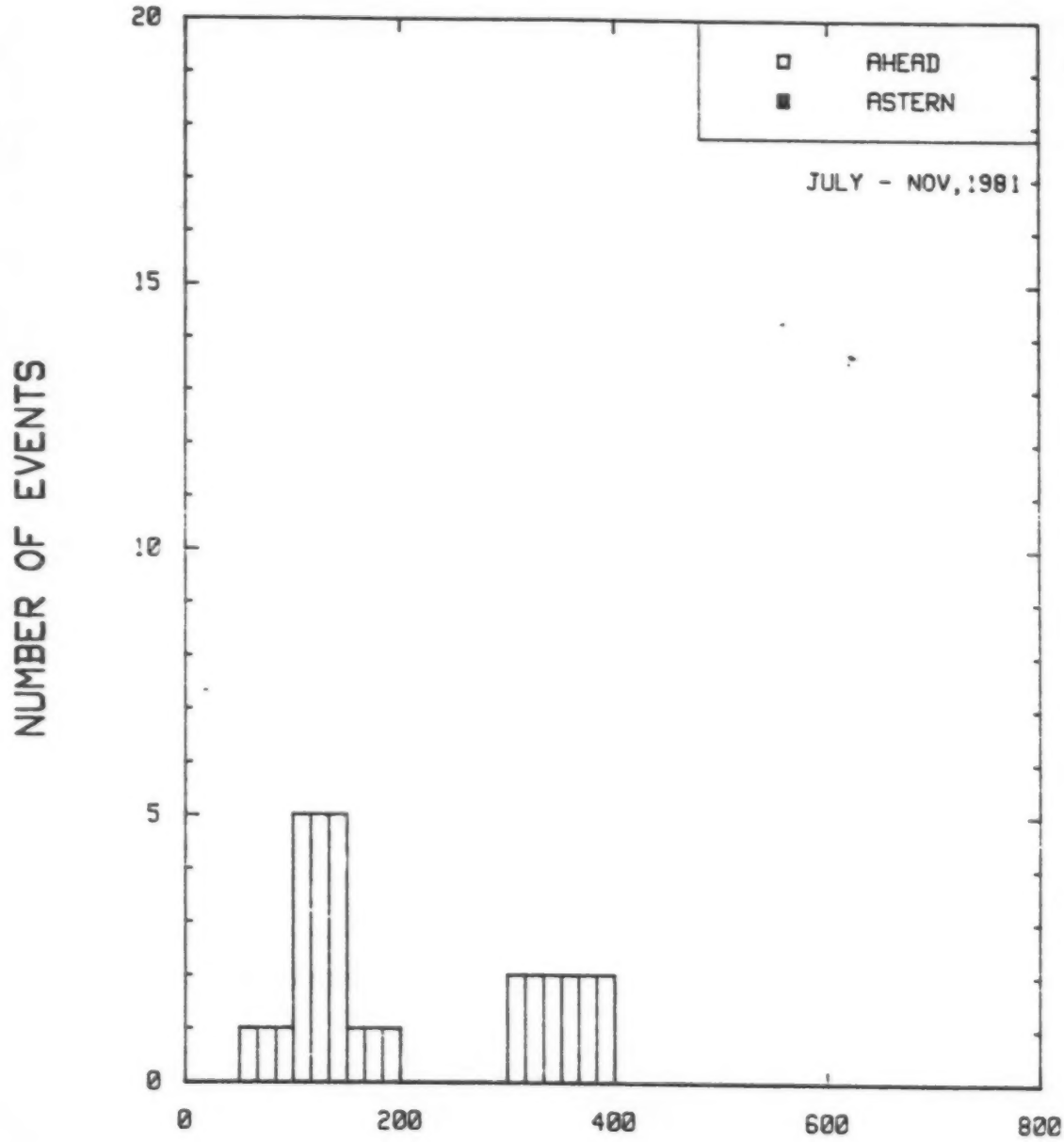

FIG. A4.36 MEASURED ICE TORQUES

(Category 2.3 : CONTINUOUS, BROKEN CHANNEL)

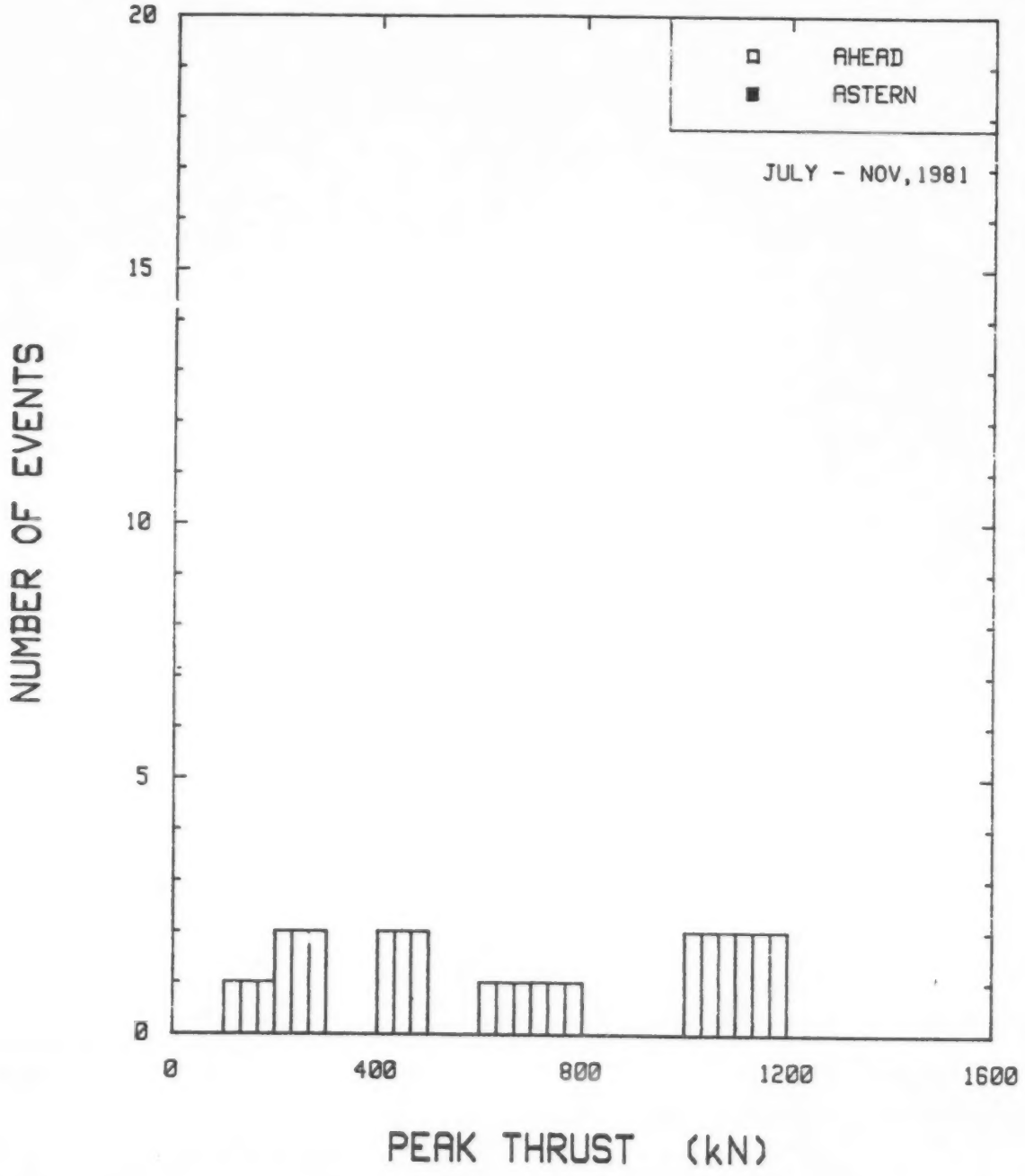

FIG. A4.37 MEASURED ICE INDUCED PEAK THRUSTS

(Category 2.3 : CONTINUOUS, BROKEN CHANNEL)

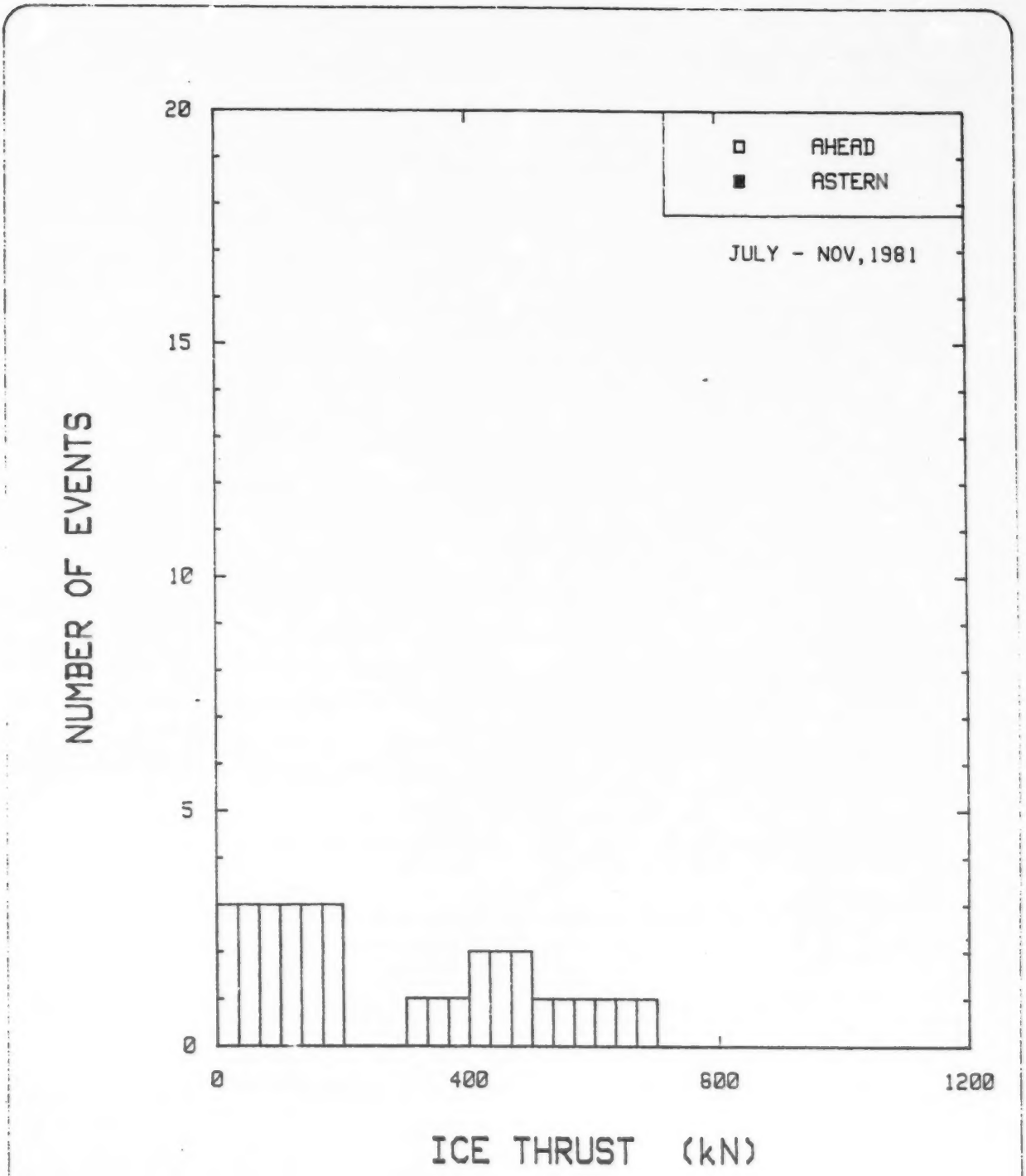

FIG. A4.38 MEASURED ICE THRUSTS

(Category 2.3 : CONTINUOUS, BROKEN CHANNEL)

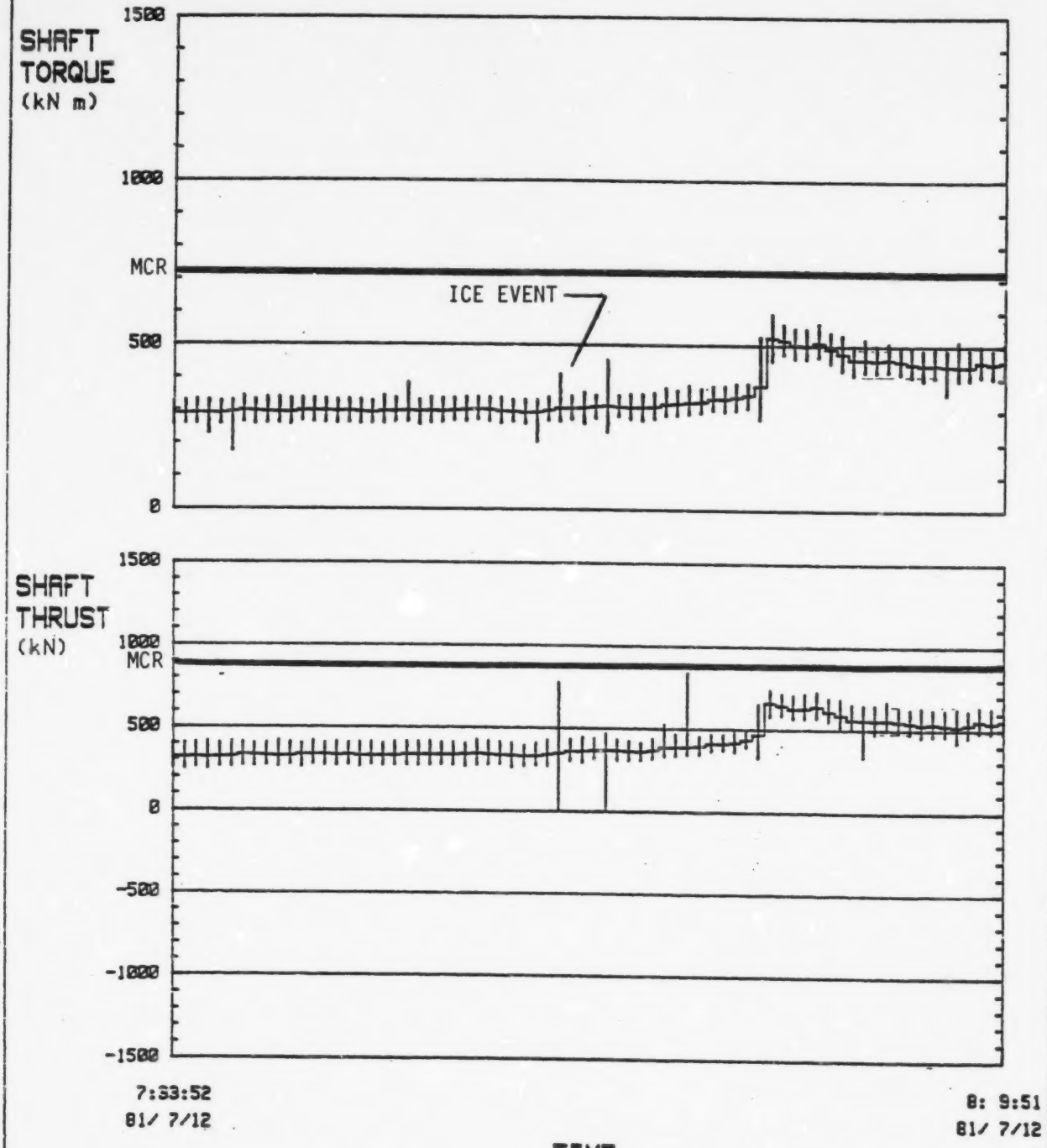

FIG. A4.39 PROPULSIVE PERFORMANCE RECORD

(BROKEN CHANNEL)

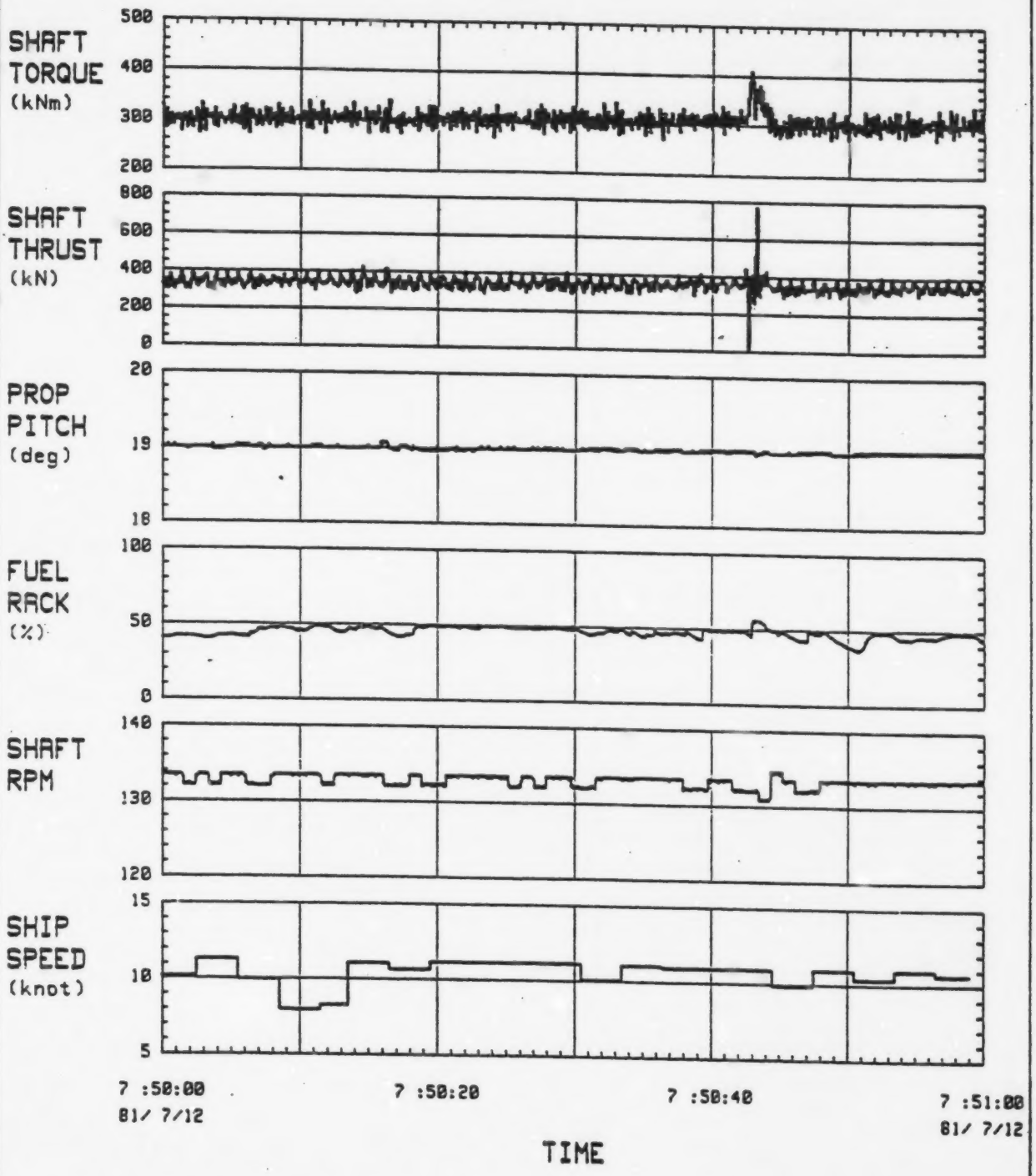

FIG. A4.40 PROPULSIVE PERFORMANCE RECORD

(BROKEN CHANNEL)

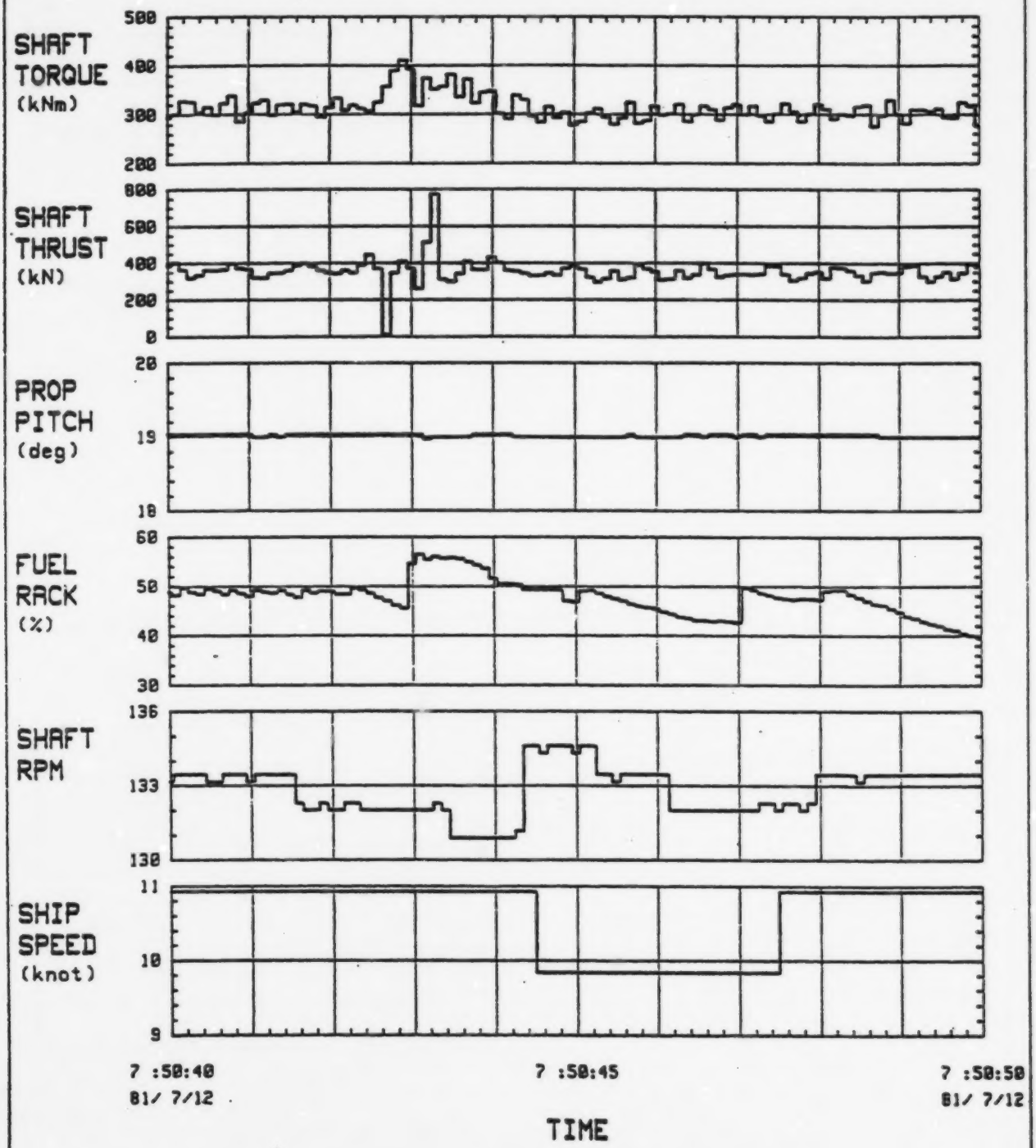

FIG. A4.41 PROPULSIVE PERFORMANCE RECORD

(BROKEN CHANNEL)

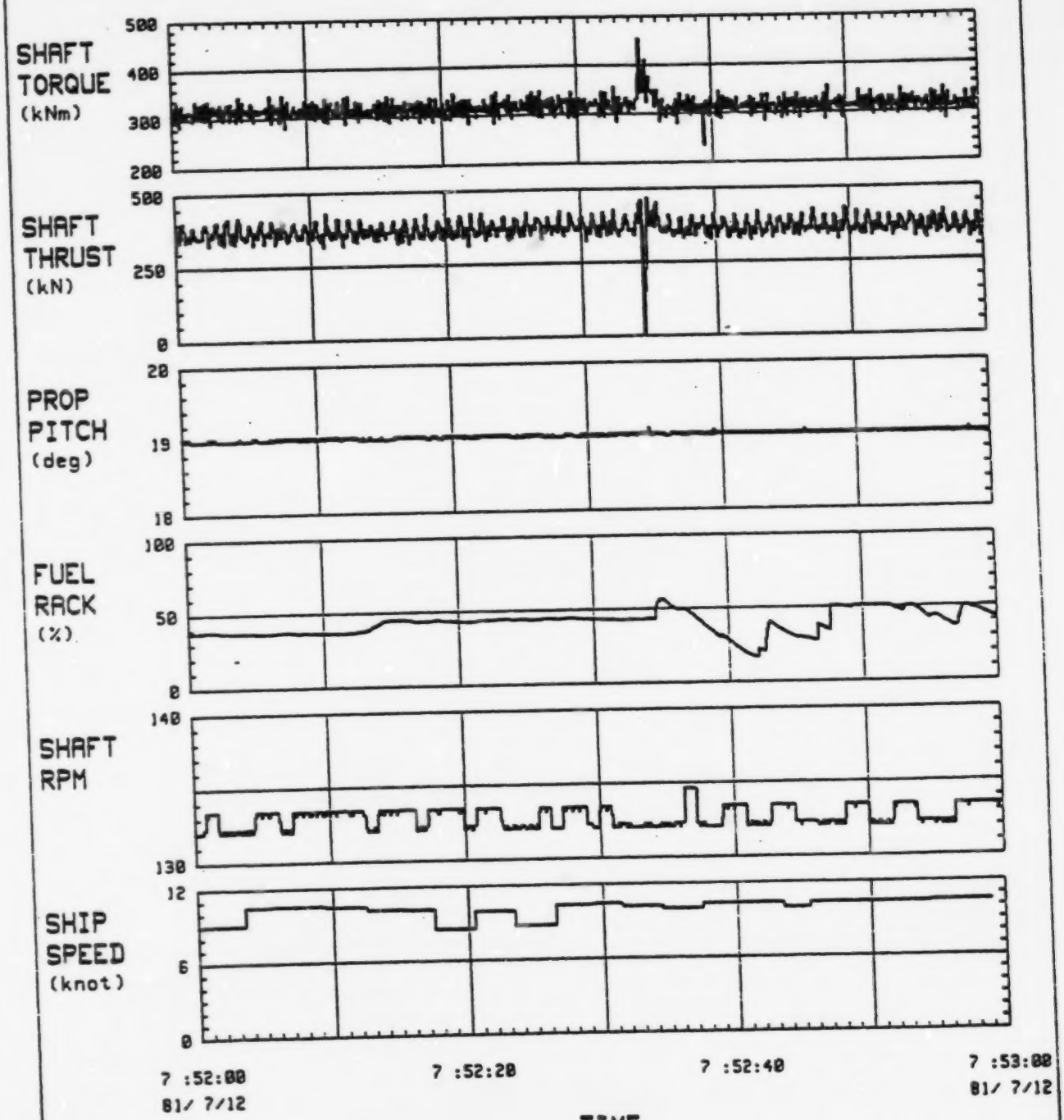

FIG. A4.42 PROPULSIVE PERFORMANCE RECORD

(BROKEN CHANNEL)

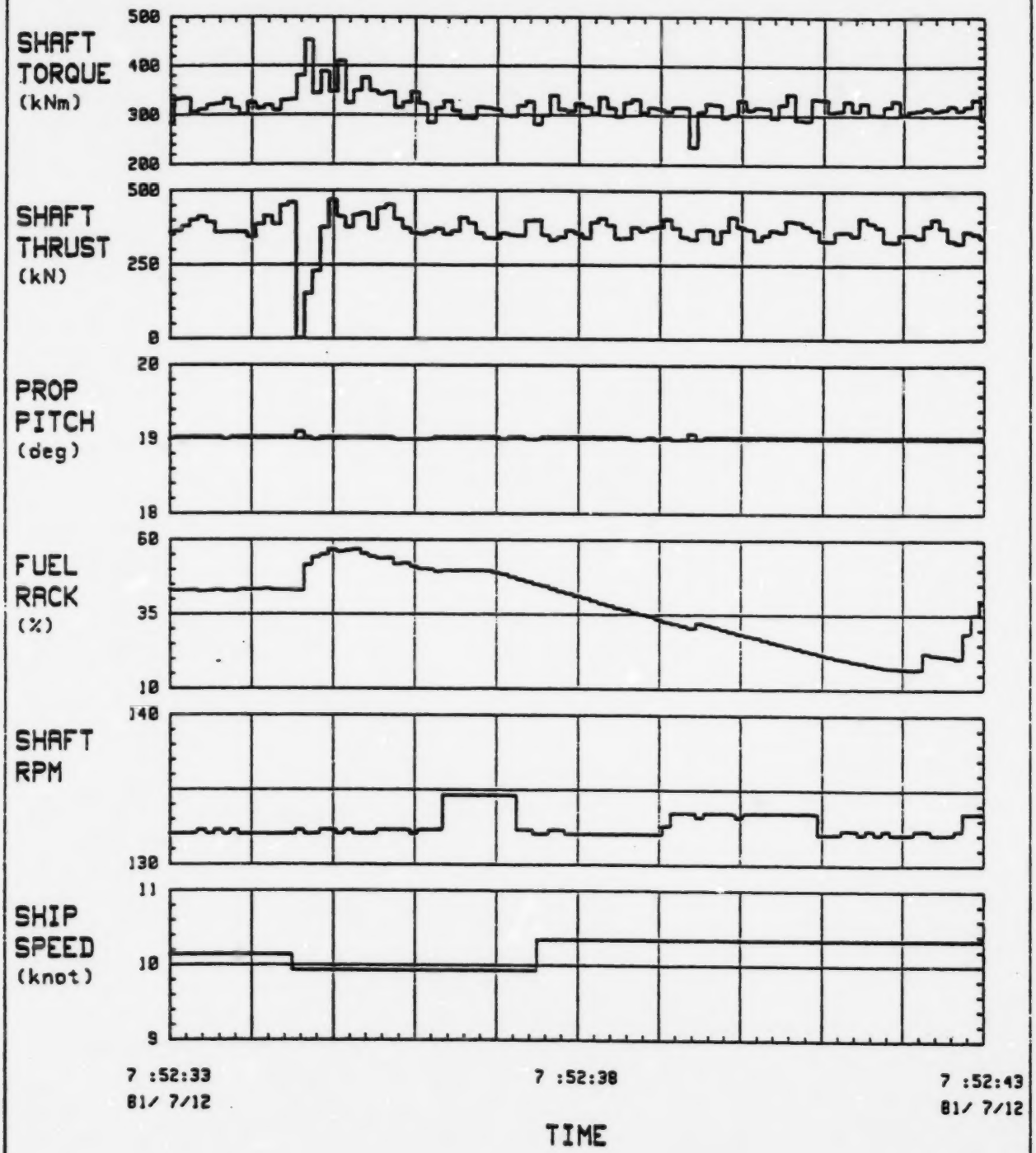

FIG. A4.43 PROPULSIVE PERFORMANCE RECORD

(BROKEN CHANNEL)

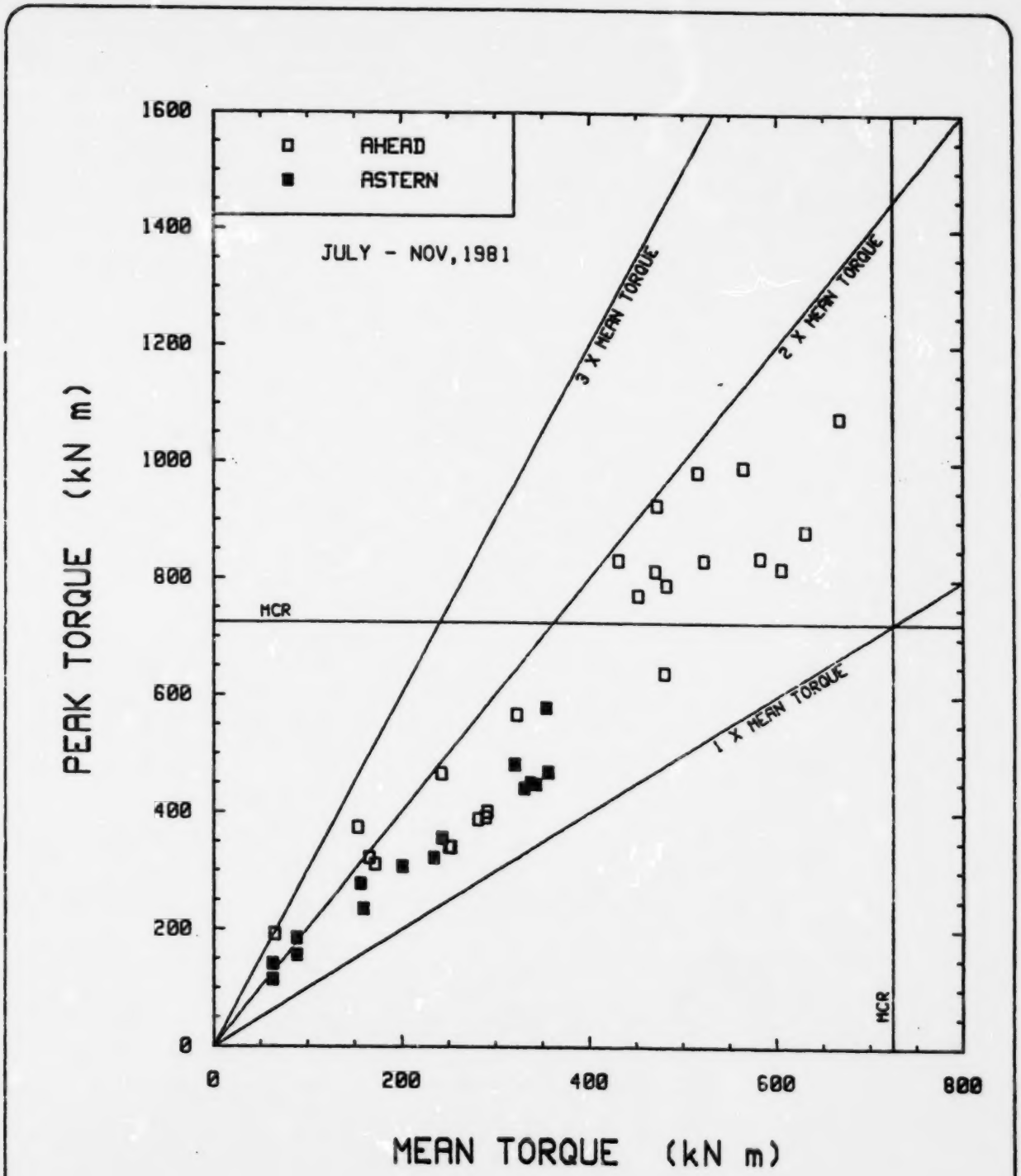

FIG. A4.44 ICE INDUCED SHAFT TORQUE EXCURSIONS

(Category 3.1 : RAMMING, LEVEL ICE)

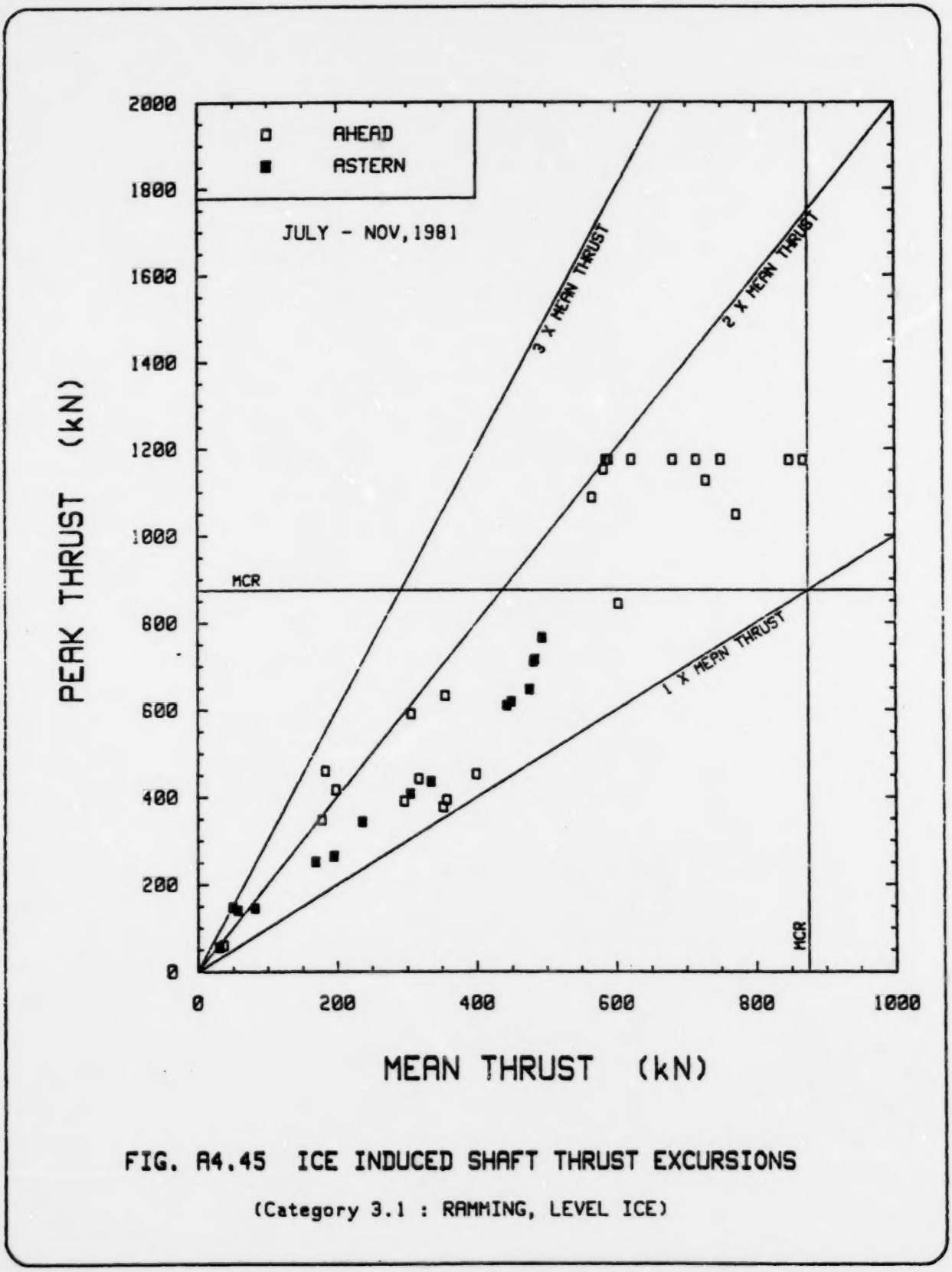

FIG. A4.45 ICE INDUCED SHAFT THRUST EXCURSIONS

(Category 3.1 : RAMMING, LEVEL ICE)

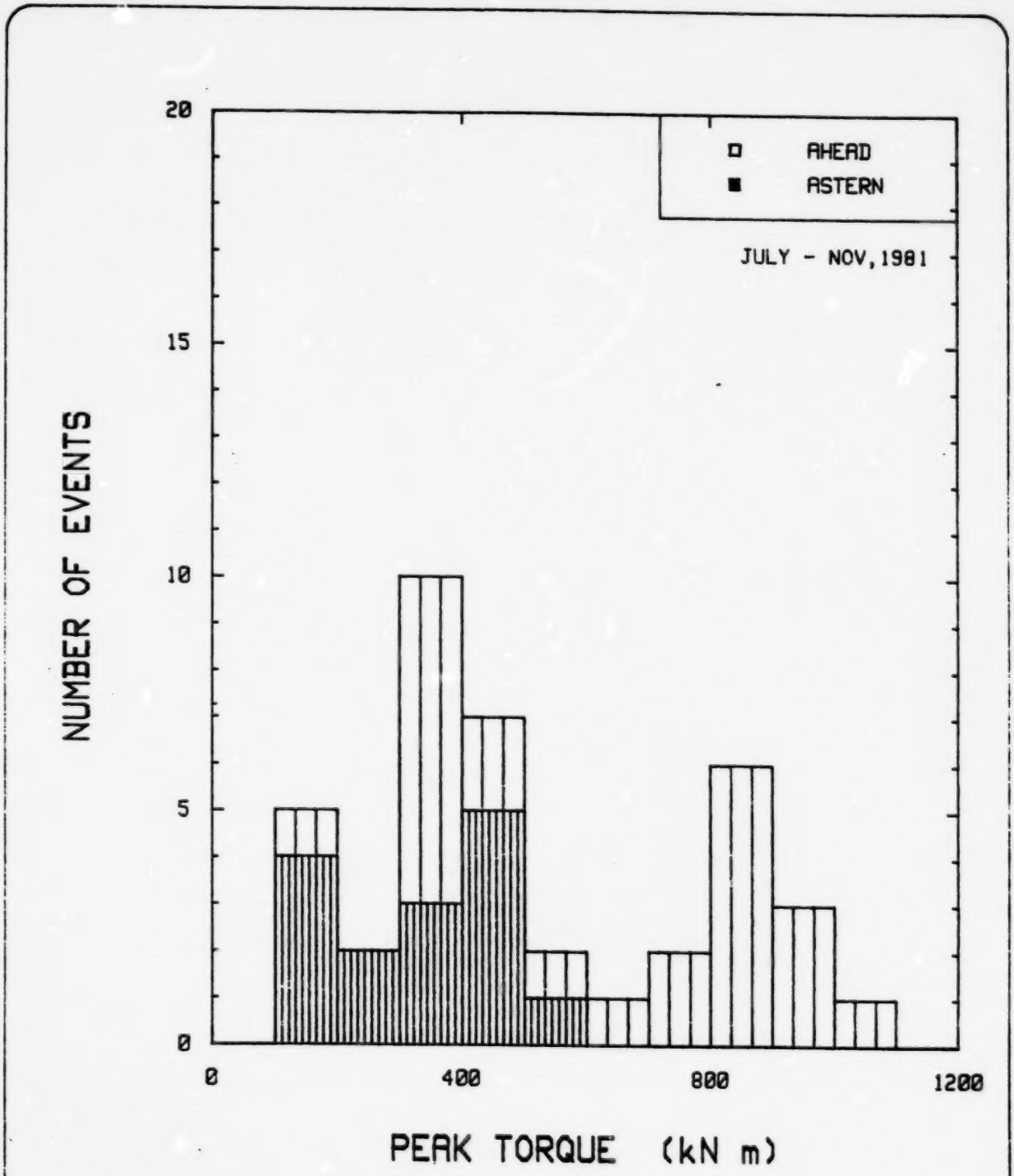

FIG. A4.46 MEASURED ICE INDUCED PEAK TORQUES

(Category 3.1 : RAMMING, LEVEL ICE)

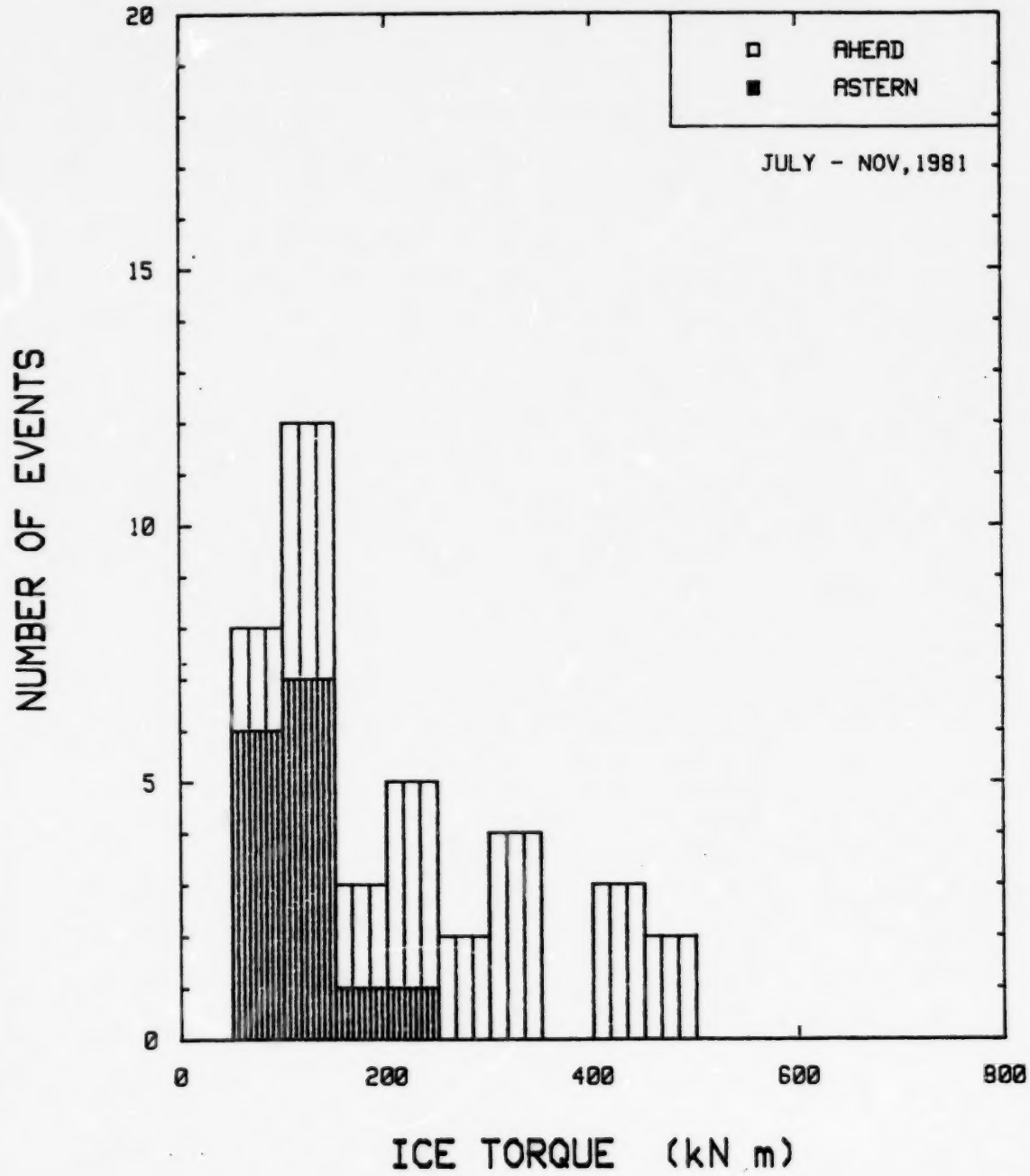

FIG. A4.47 MEASURED ICE TORQUES

(Category 3.1 : RAMMING, LEVEL ICE)

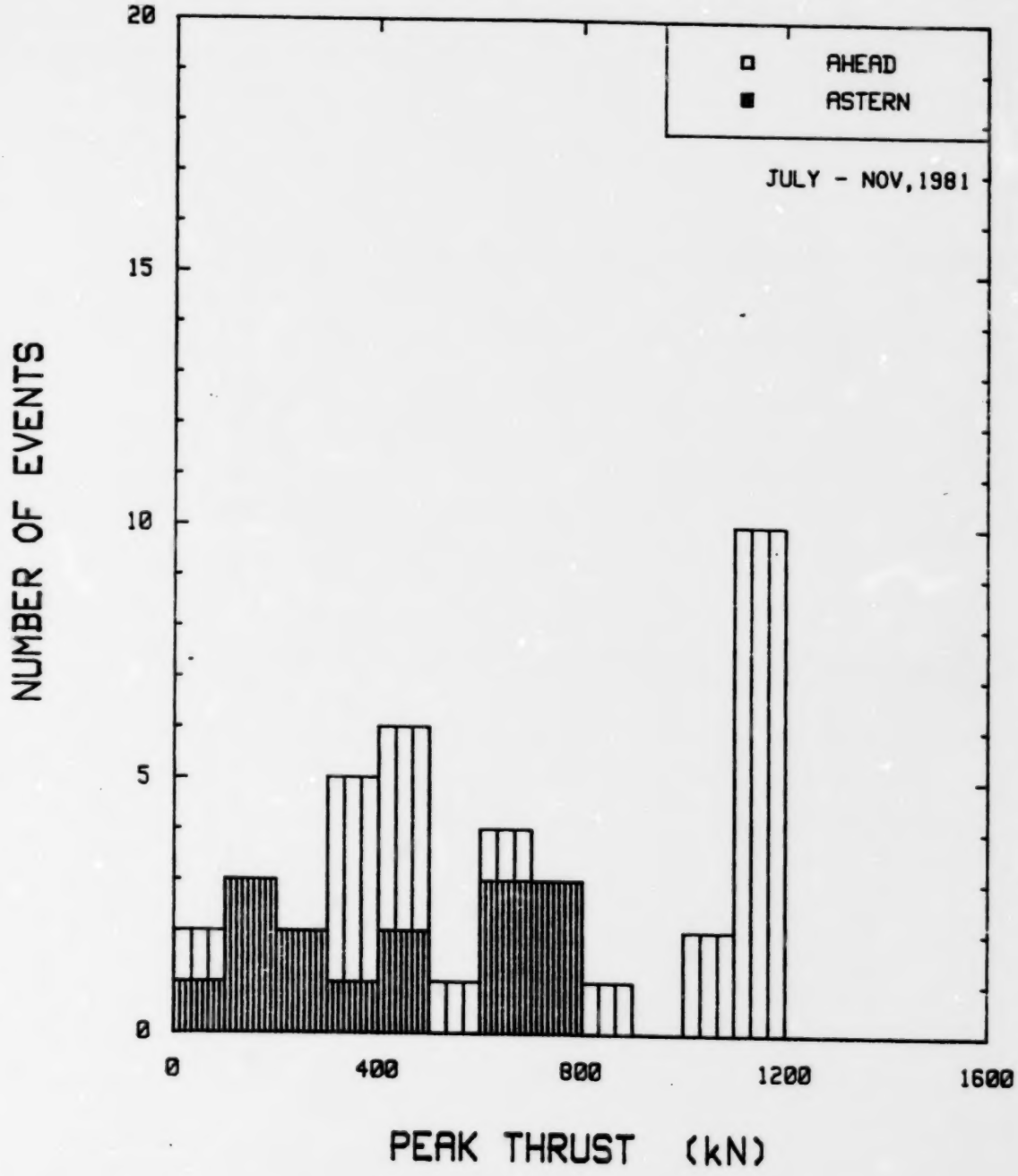

FIG. A4.48 MEASURED ICE INDUCED PEAK THRUSTS

(Category 3.1 : RAMMING, LEVEL ICE)

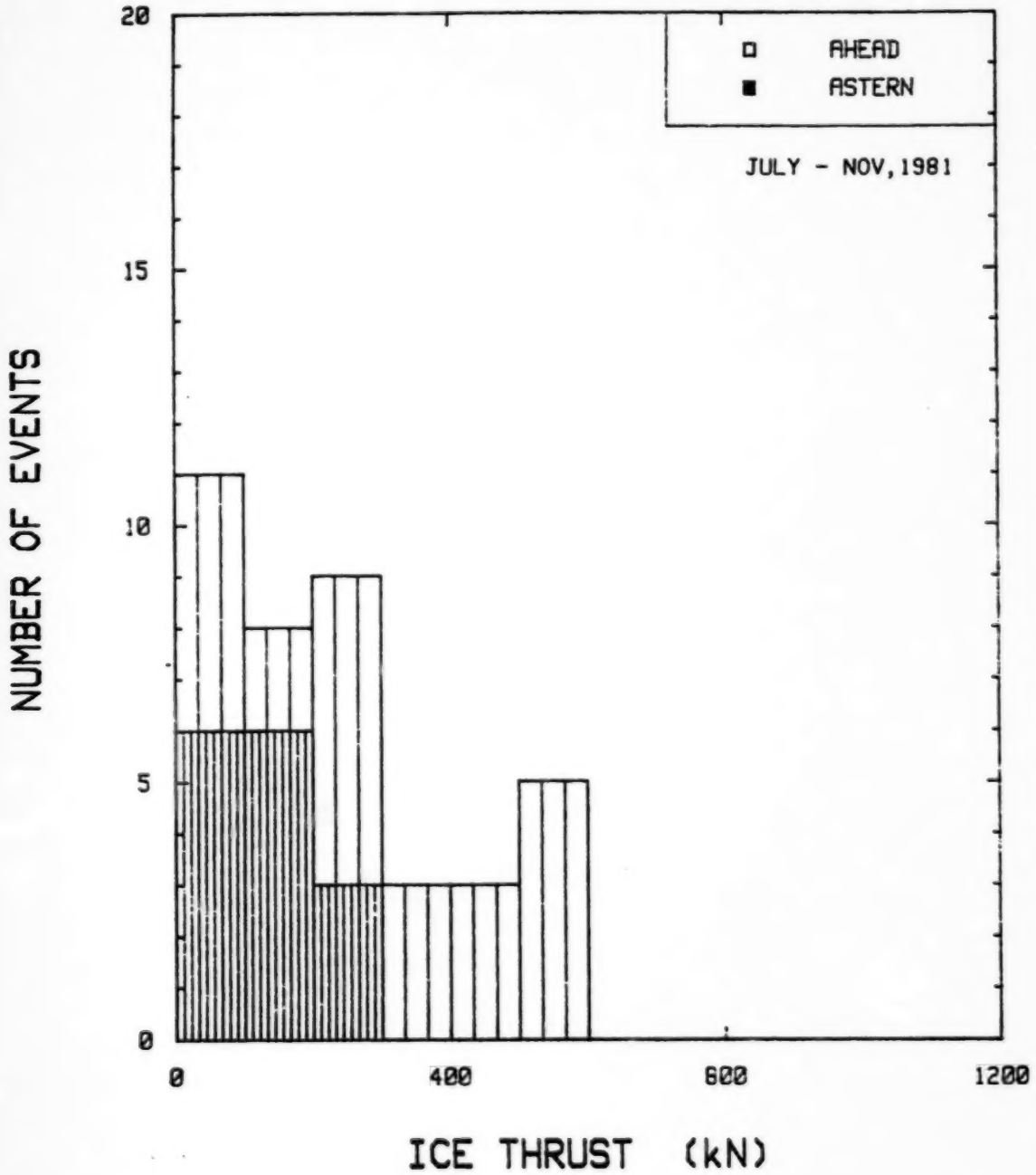

FIG. A4.49 MEASURED ICE THRUSTS

(Category 3.1 : RAMMING, LEVEL ICE)

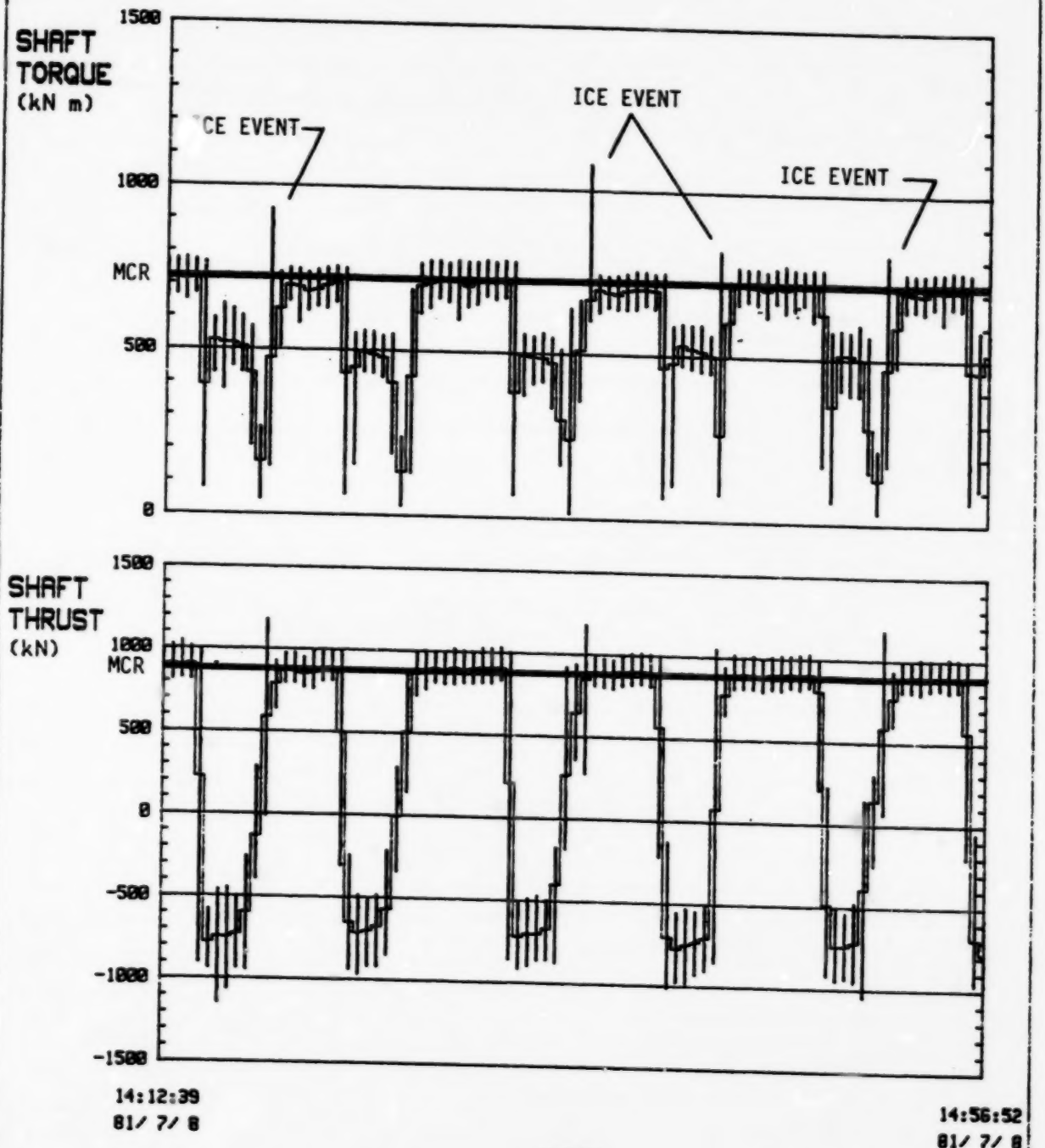

FIG. A4.50 PROPULSIVE PERFORMANCE RECORD

(RAMMING, LEVEL ICE)

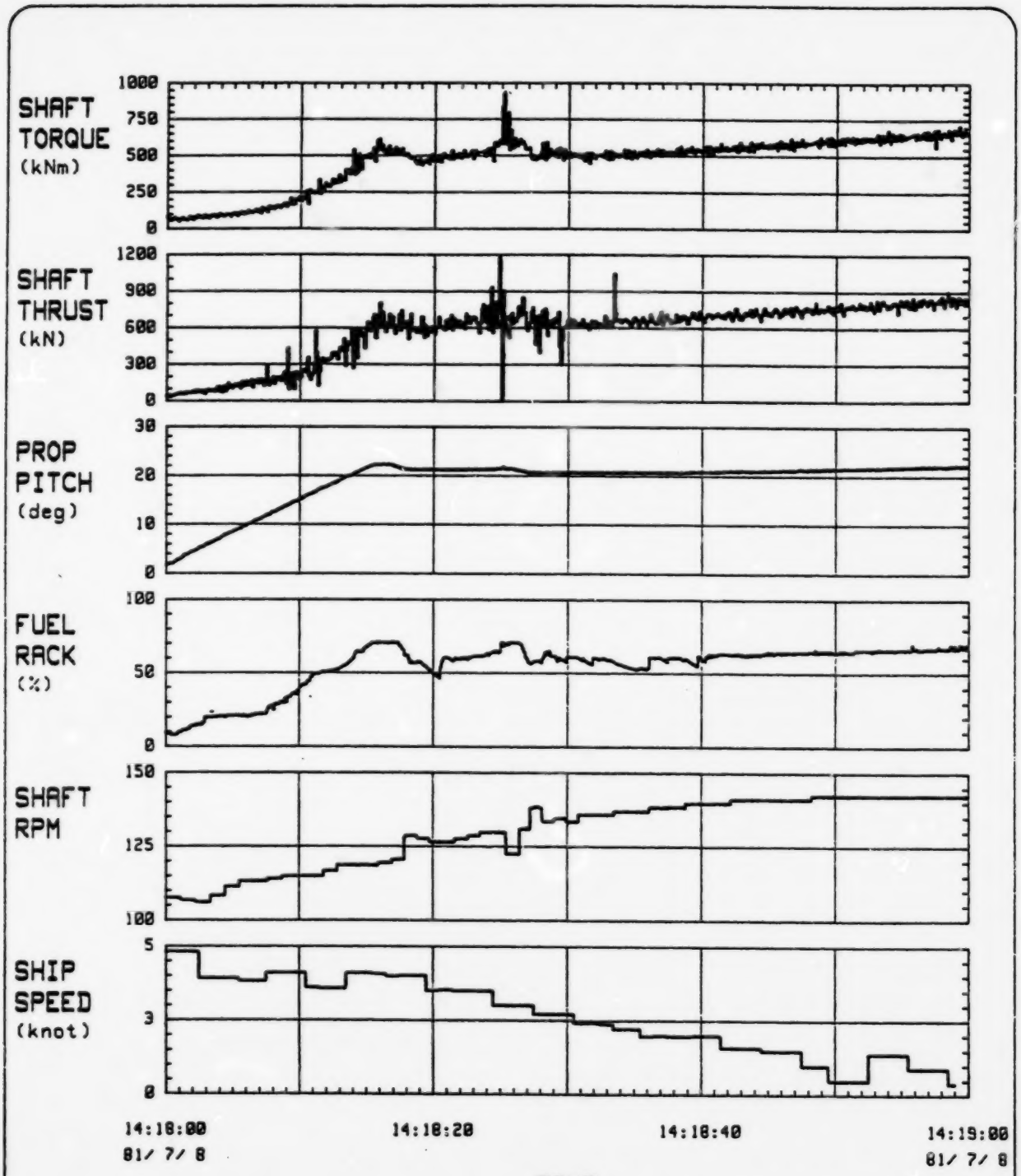

FIG. A4.51 PROPULSIVE PERFORMANCE RECORD

(RAMMING, LEVEL ICE)

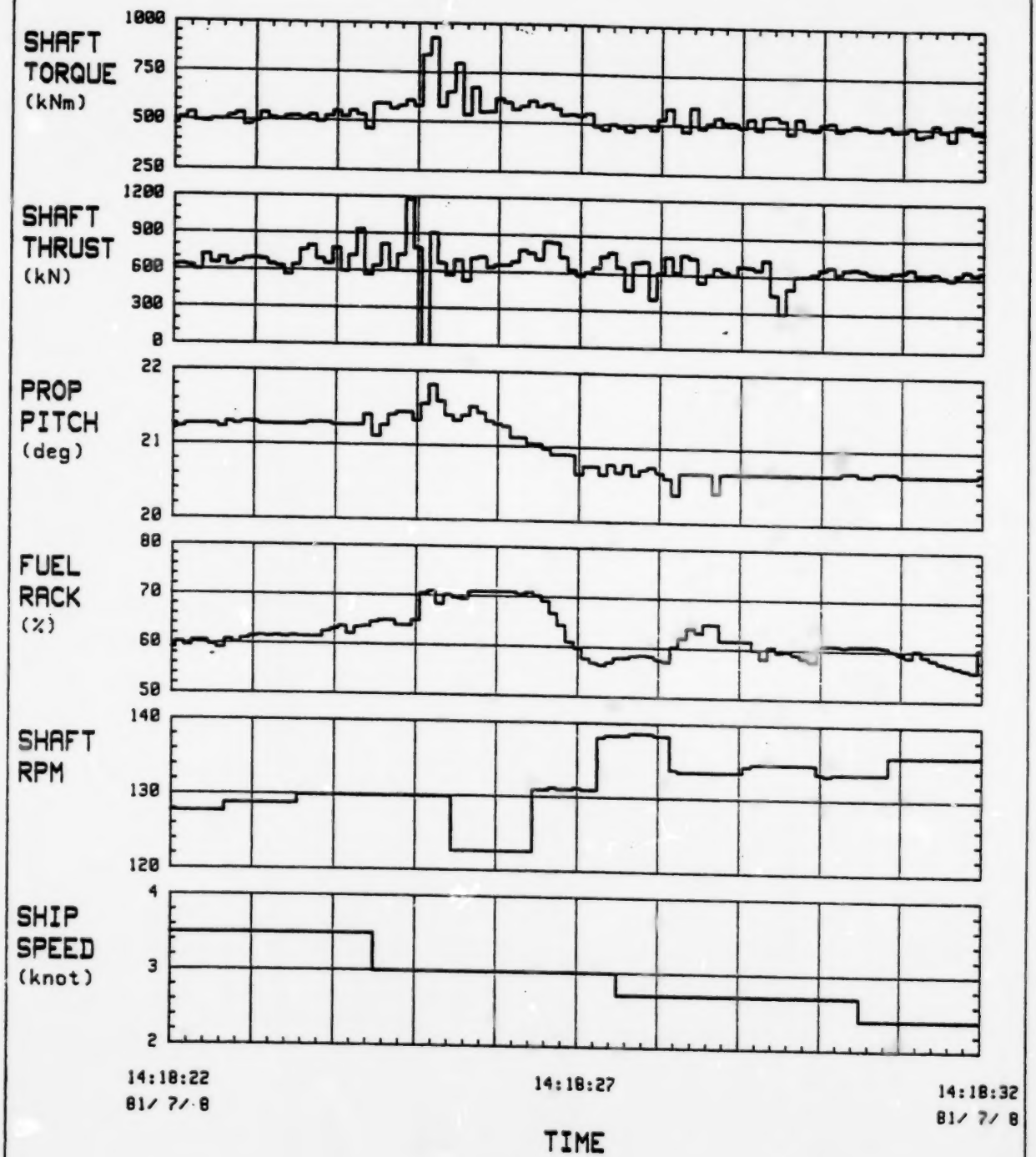

FIG. A4.52 PROPULSIVE PERFORMANCE RECORD

(RAMMING, LEVEL ICE)

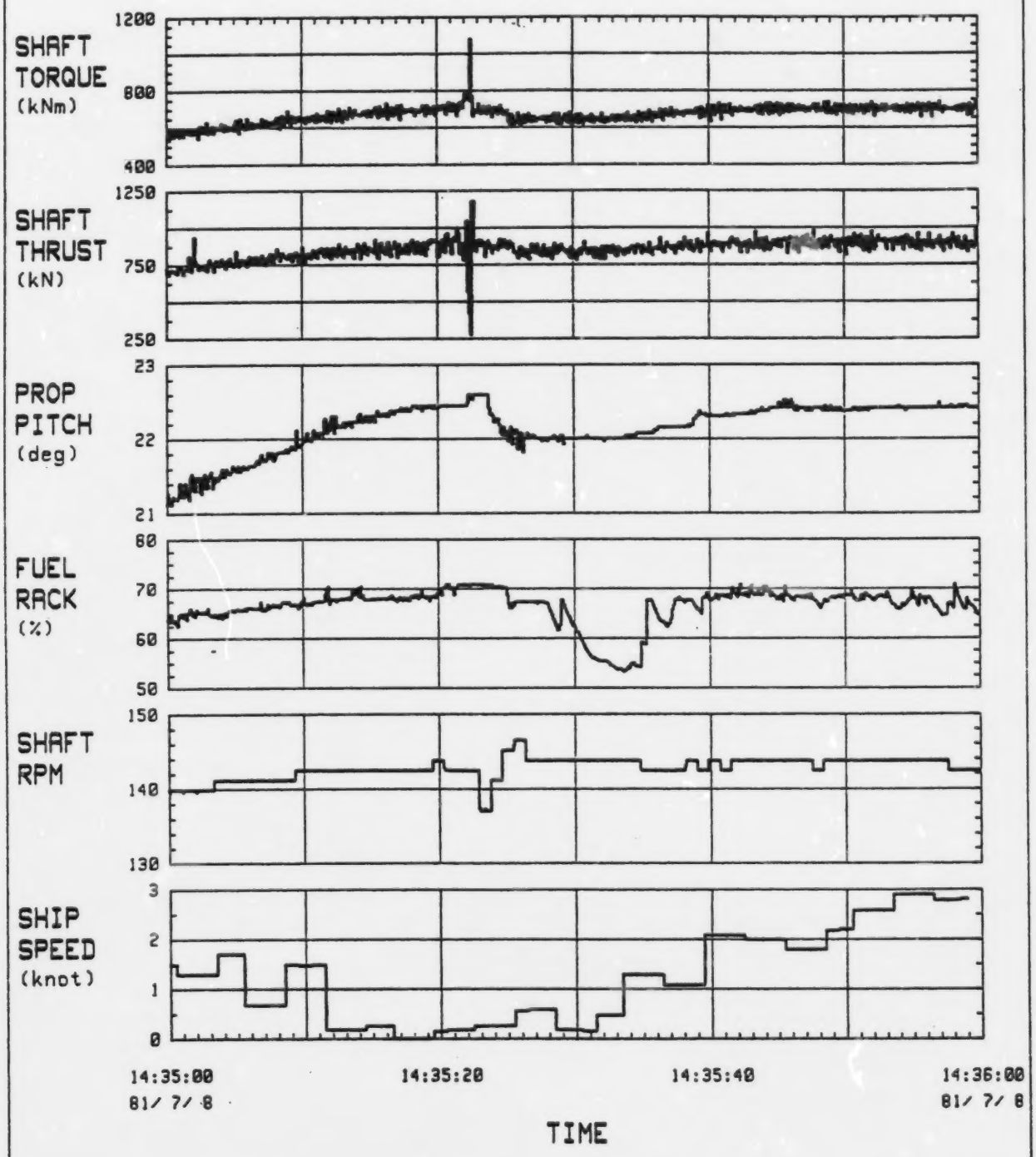

FIG. A4.53 PROPULSIVE PERFORMANCE RECORD

(RAMMING, LEVEL ICE)

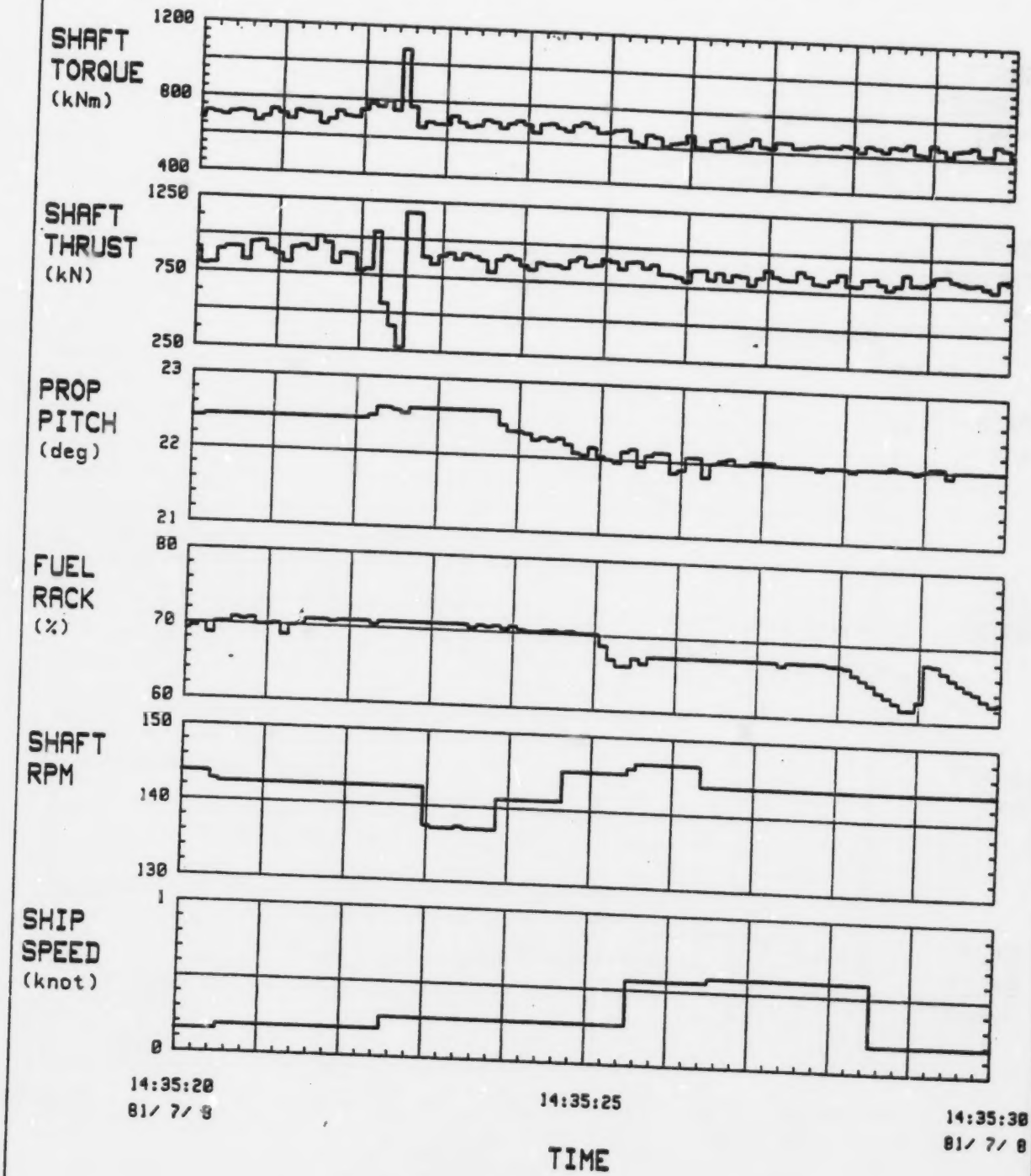

FIG. A4.54 PROPULSIVE PERFORMANCE RECORD

(RAMMING, LEVEL ICE)

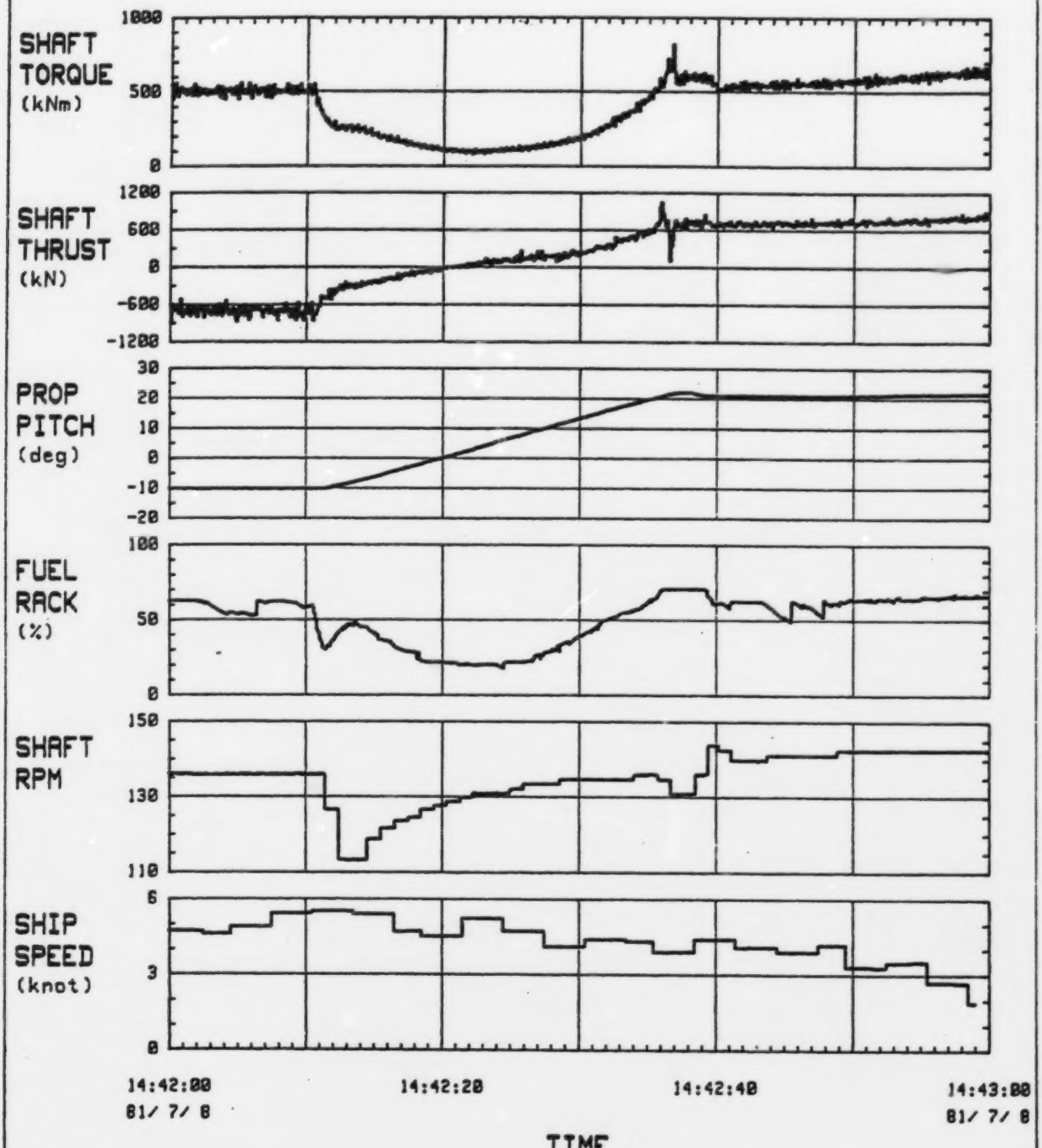

FIG. A4.55 PROPULSIVE PERFORMANCE RECORD

(RAMMING, LEVEL ICE)

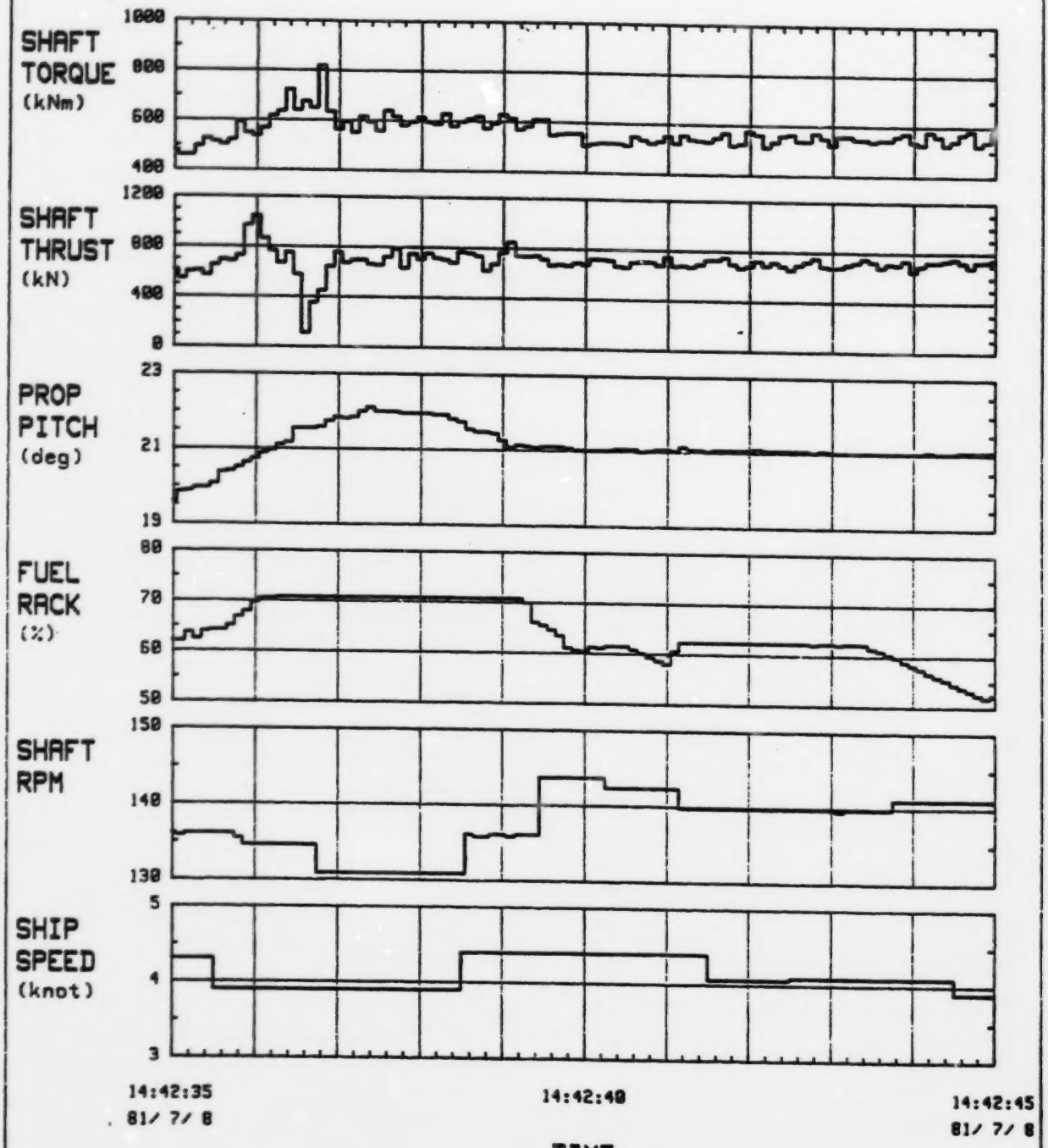

FIG. A4.56 PROPULSIVE PERFORMANCE RECORD

(RAMMING, LEVEL ICE)

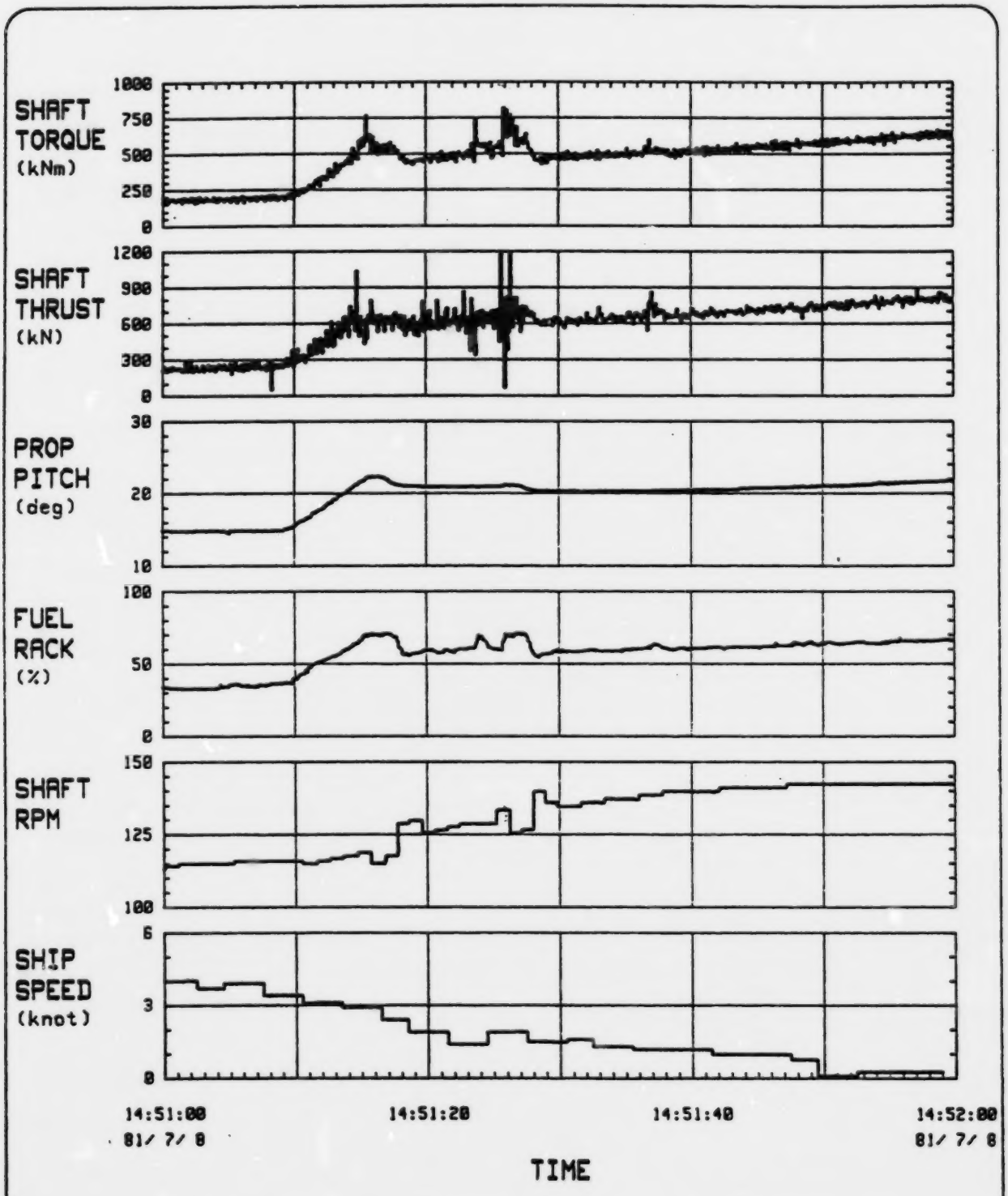

FIG. A4.57 PROPULSIVE PERFORMANCE RECORD

(RAMMING, LEVEL ICE)

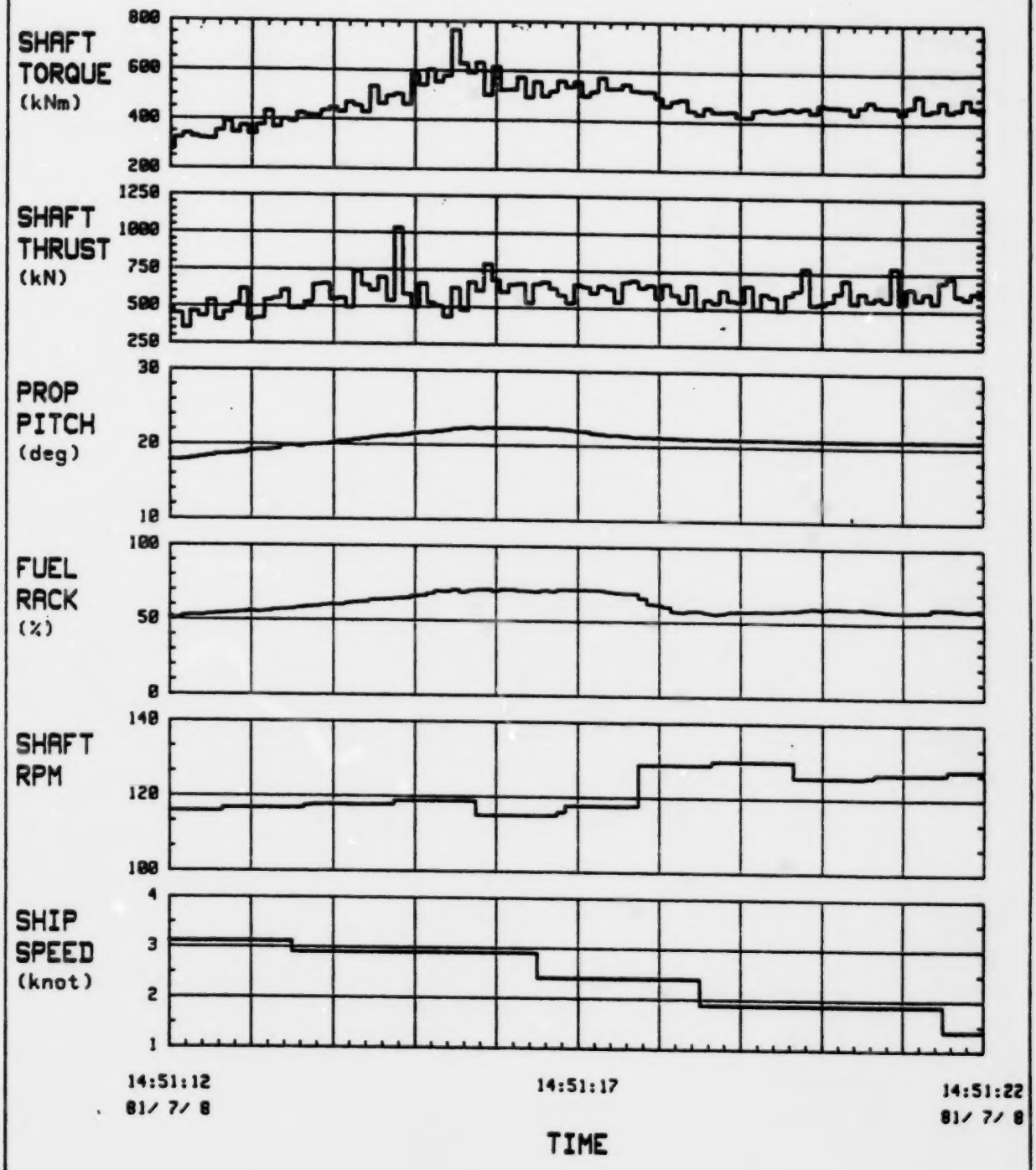

FIG. A4.58 PROPULSIVE PERFORMANCE RECORD

(RAMMING, LEVEL ICE)

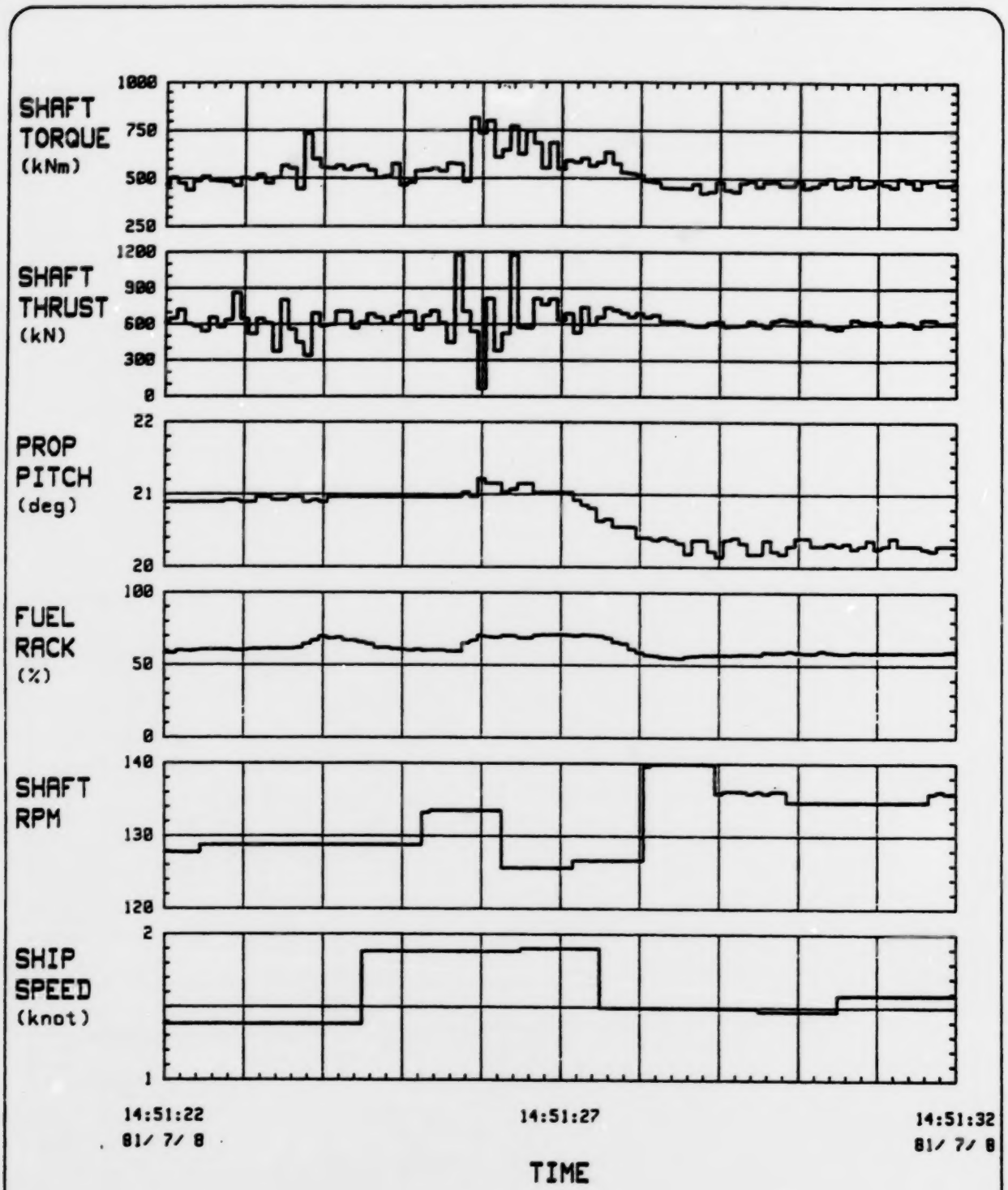

FIG. A4.59 PROPULSIVE PERFORMANCE RECORD

(RAMMING, LEVEL ICE)

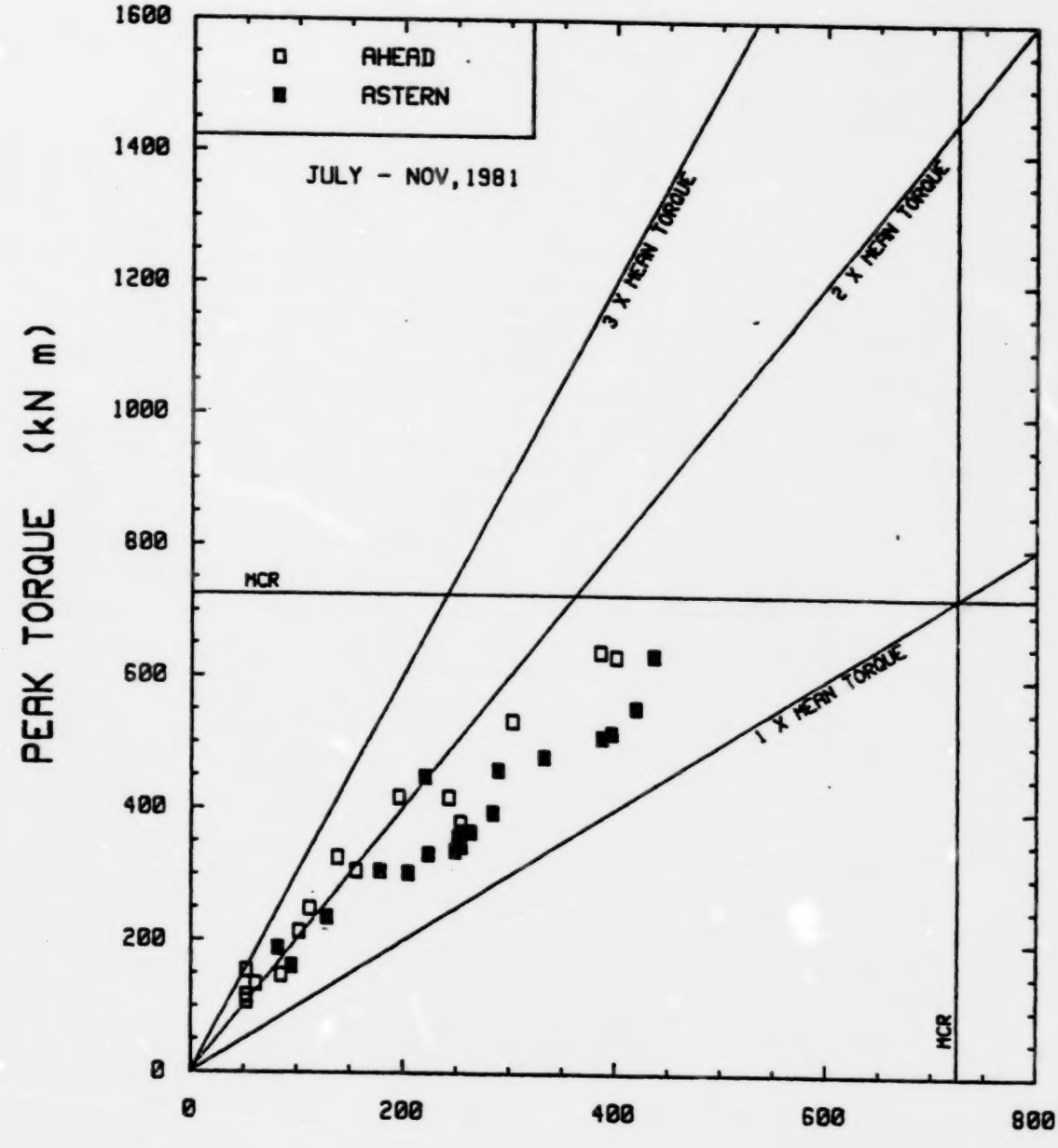

FIG. A4.60 ICE INDUCED SHAFT TORQUE EXCURSIONS

(Category 3.2 : RAMMING, RIDGES)

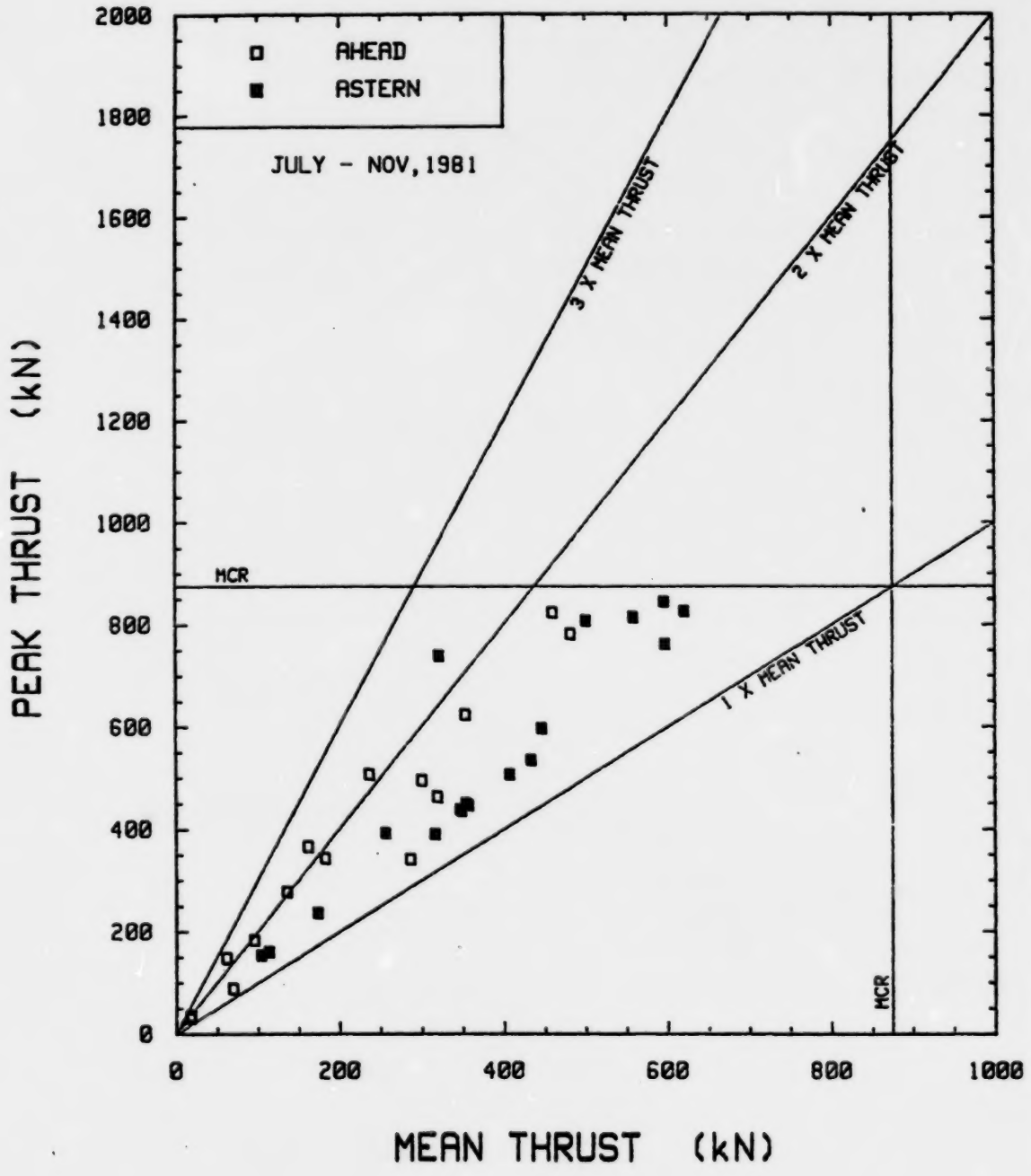

FIG. A4.61 ICE INDUCED SHAFT THRUST EXCURSIONS

(Category 3.2 : RAMMING, RIDGES)

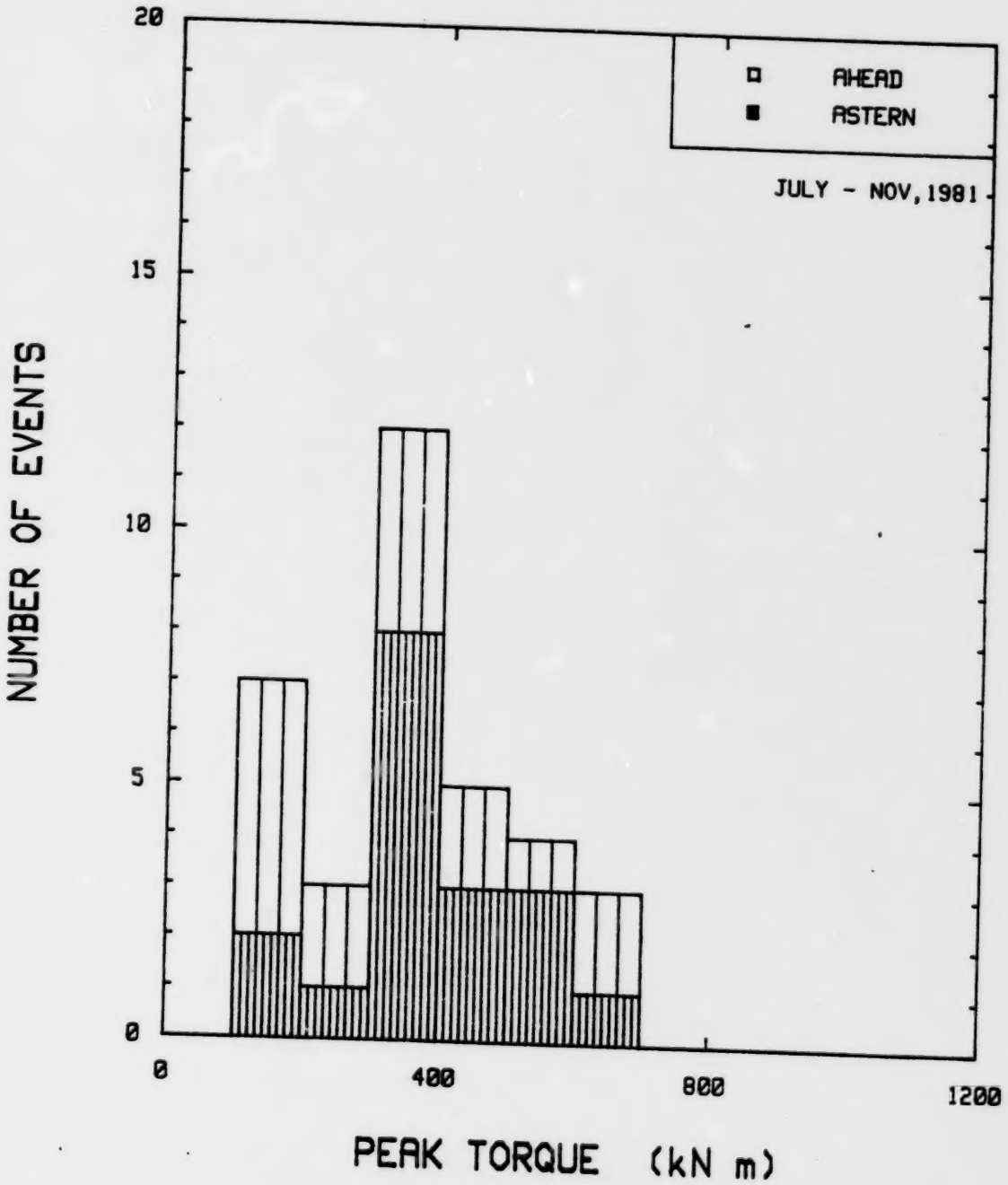

FIG. A4.62 MEASURED ICE INDUCED PEAK TORQUES

(Category 3.2 : RAMMING, RIDGES)

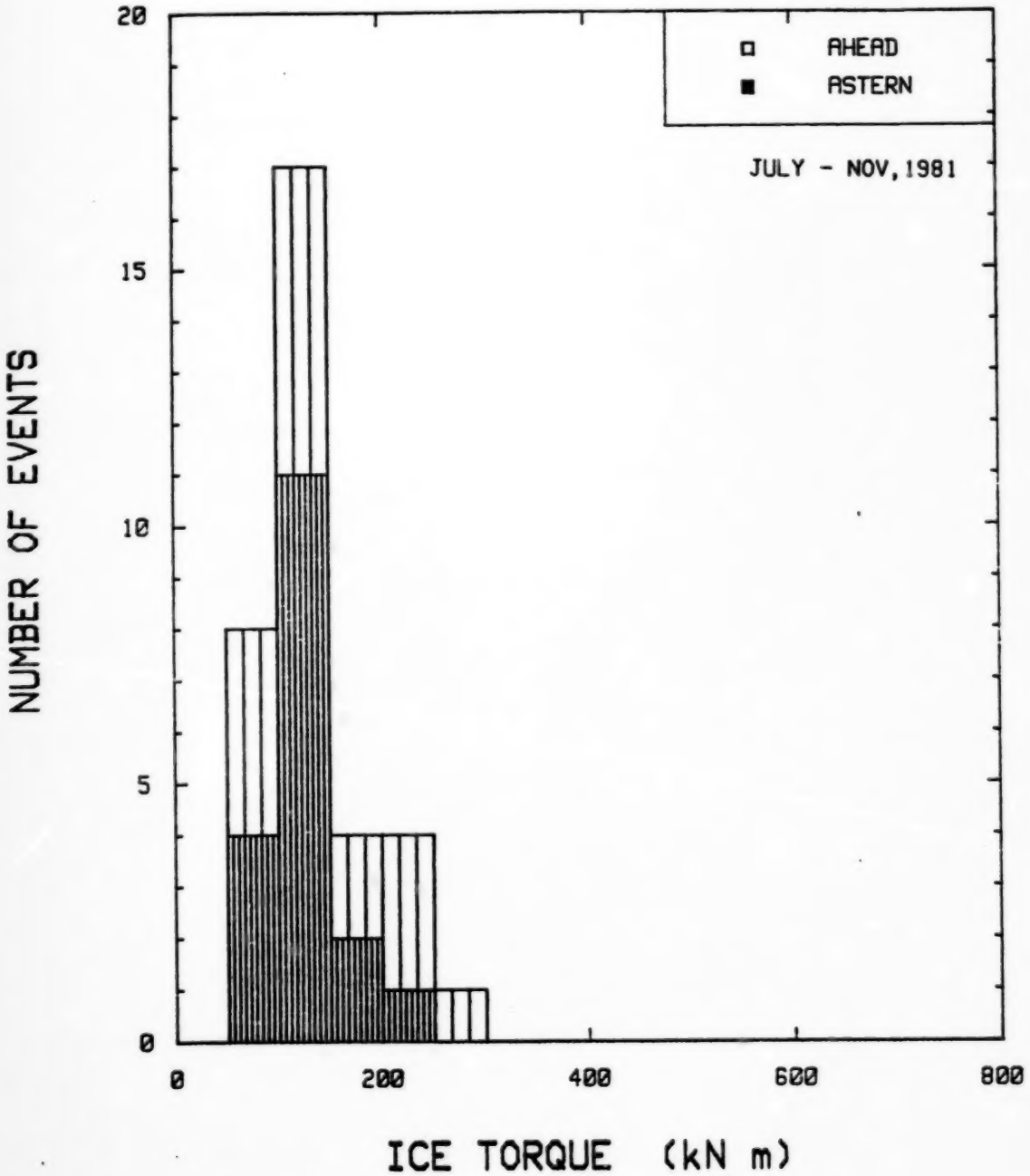

FIG. A4.63 MEASURED ICE TORQUES

(Category 3.2 : RAMMING, RIDGES)

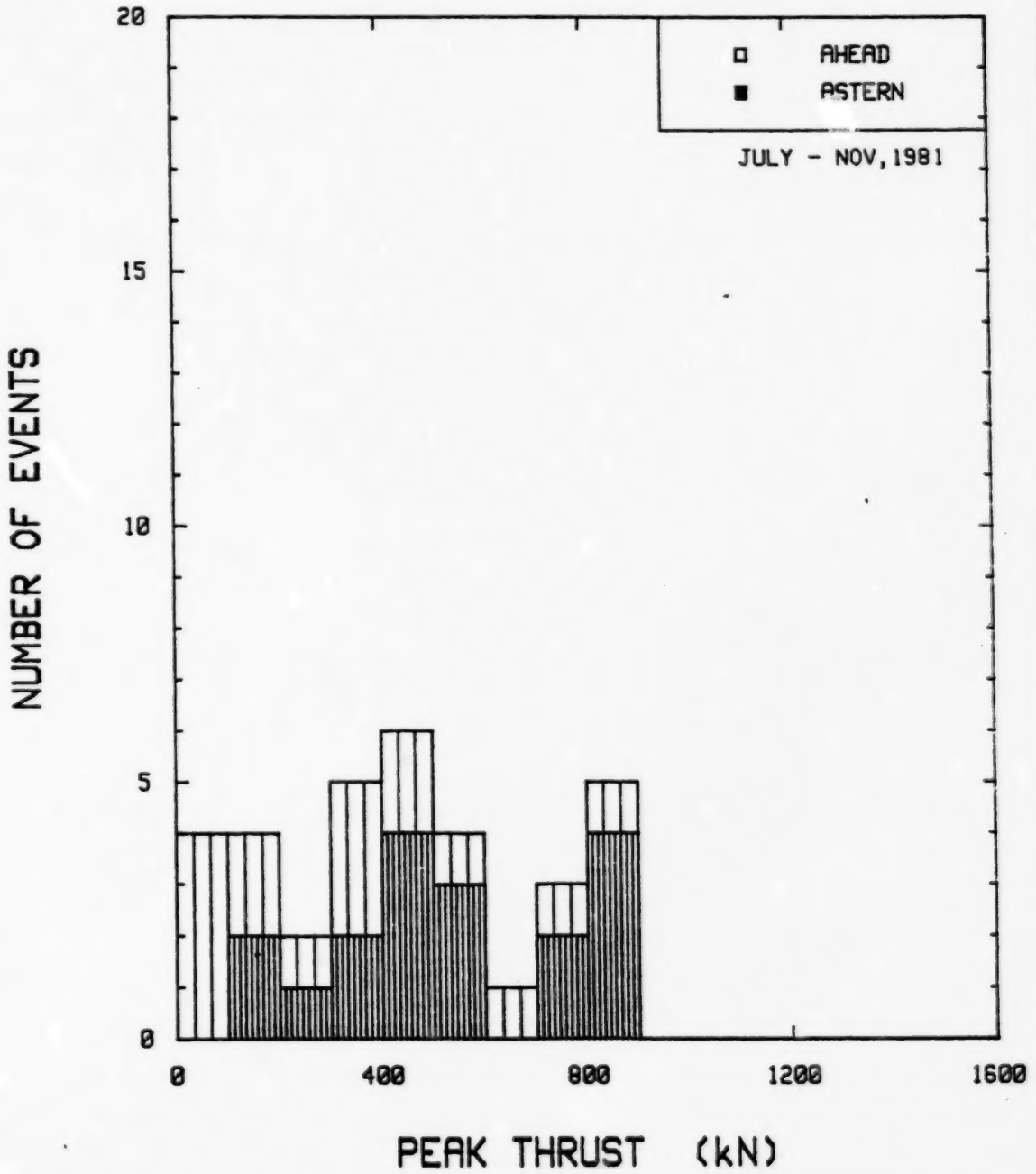

FIG. A4.64 MEASURED ICE INDUCED PEAK THRUSTS

(Category 3.2 : RAMMING, RIDGES)

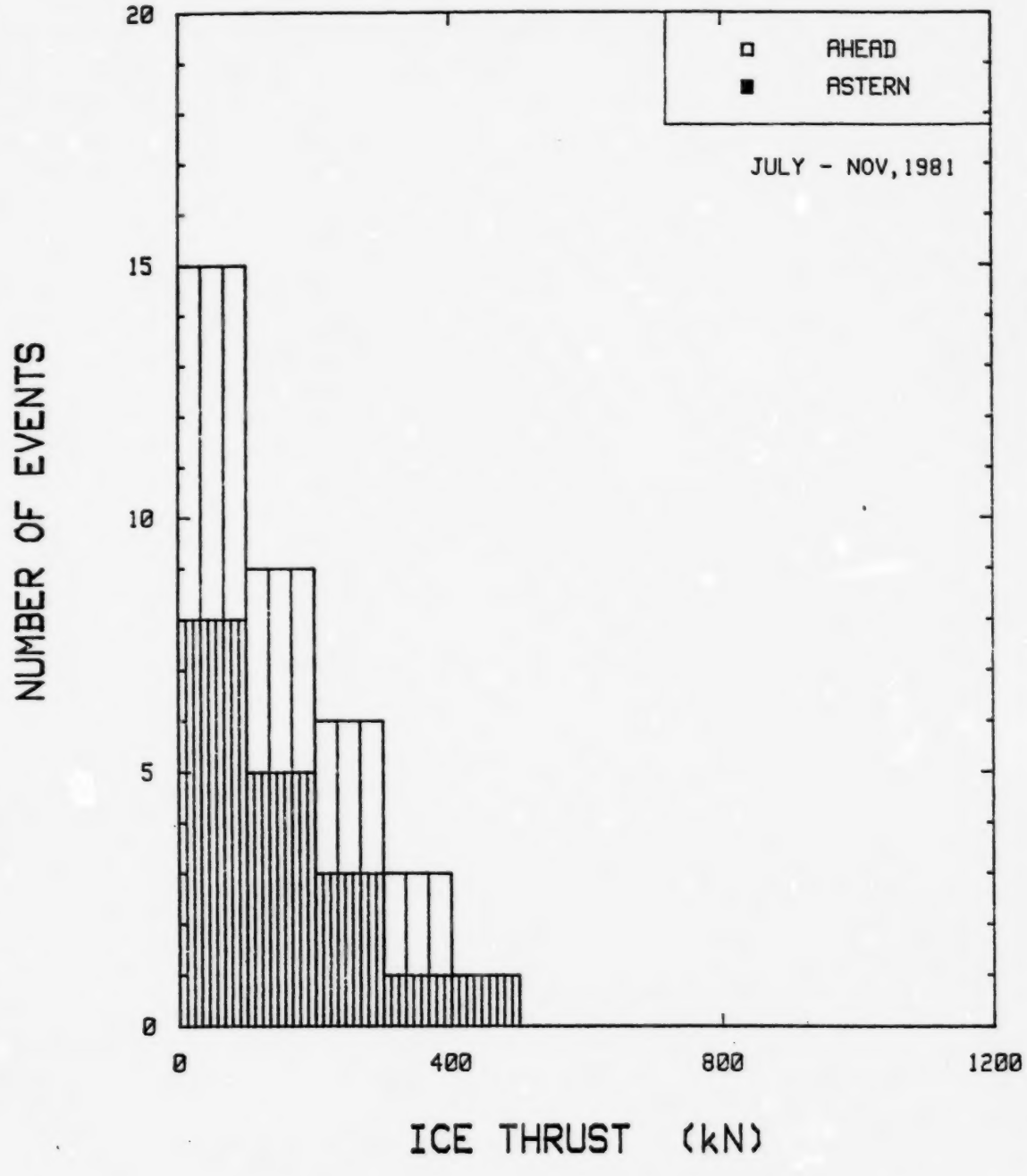

FIG. A4.65 MEASURED ICE THRUSTS

(Category 3.2 : RAMMING, RIDGES)

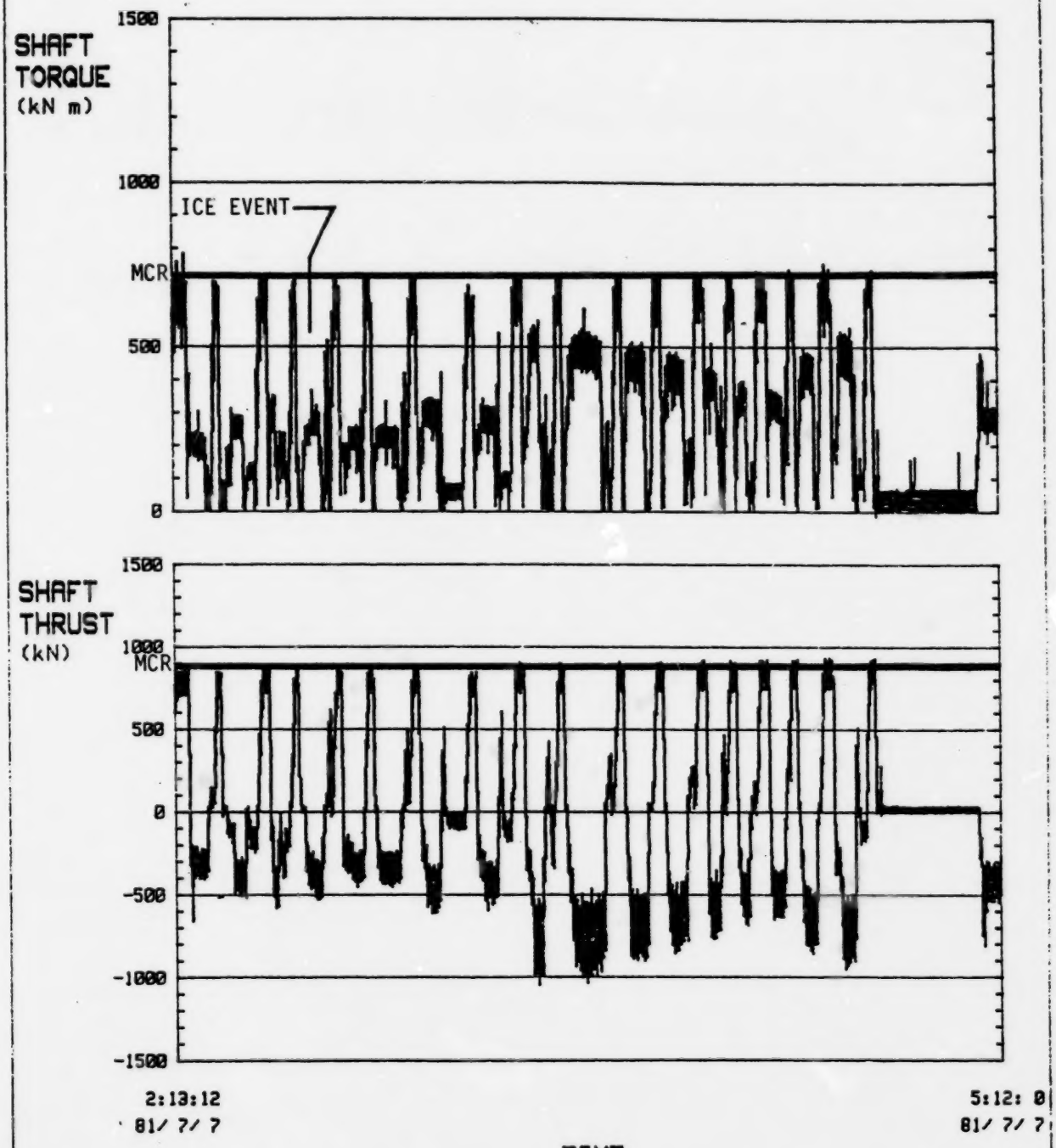

FIG. A4.66 PROPULSIVE PERFORMANCE RECORD

(RAMMING, RIDGES)

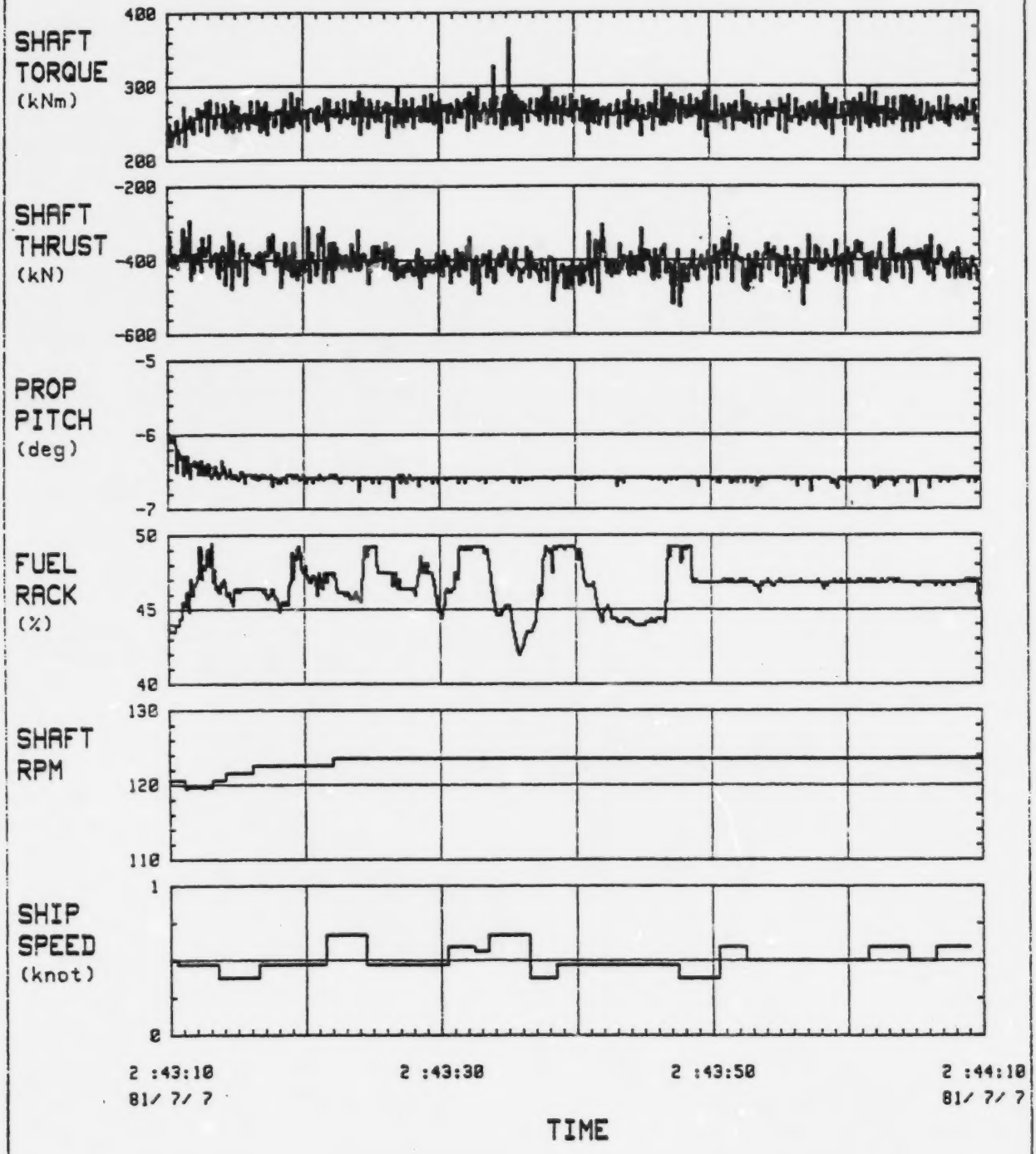

FIG. A4.67 PROPULSIVE PERFORMANCE RECORD

(RAMMING, RIDGES)

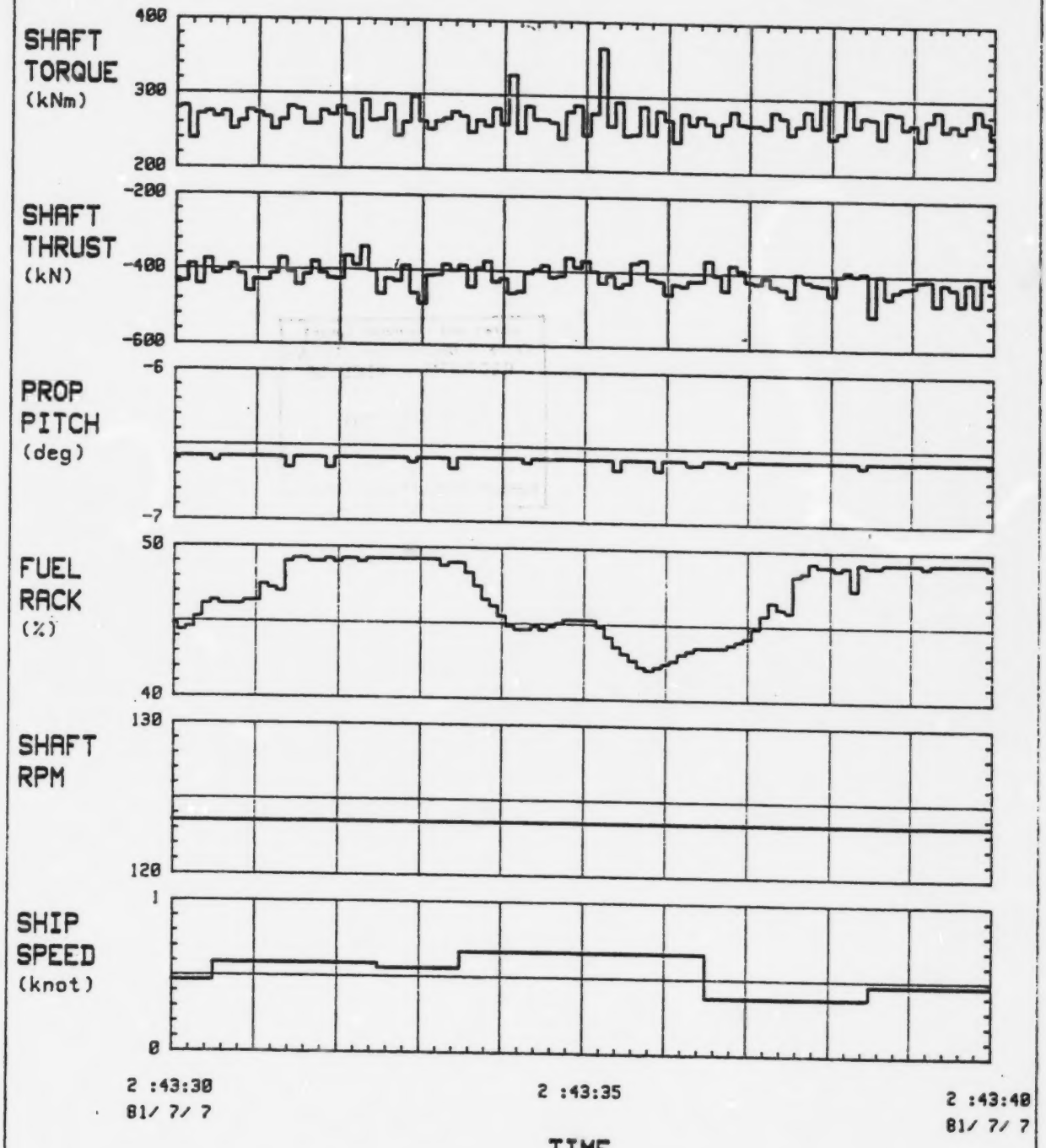

FIG. A4.68 PROPULSIVE PERFORMANCE RECORD

(RAMMING, RIDGES)